Performance Analysis of a PV Grid-connected System at the Universidade Nacional Timor Lorosa’e

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Abstract

The increasing energy demand in developing countries has initiated the issue of energy security. This has made important to develop the unexploited potential of renewable resources in latest years, including which Solar Energy stands out. Its growing interest and enactment have led to an increase of technological improvement of these systems, which has allowed a significant decrease of their costs, and an increase in their economic capability. PV growth for power generation is one of the highest in the field of renewable energies and this tendency is expected to continue to growth in the coming years. As PV power becomes more affordable, the uses of PV for grid-connected applications are increasing. The transition towards PV as a competitive technology will be necessary to take place in most of the energy markets. This process requires to be complemented by a realistic evaluation of installed power plants, with credible information and reliable recommendations.

In this study, the evaluation of performance of a micro grid-connected system is conducted and simulation for connected with the battery and sensitivity analysis of load fluctuation are presented. This PV system is installed in the Faculty of Engineering, Science, and Technology (FEST) buildings of the Universidade Nacional Timor Lorosa´e (UNTL), located in Dili, Timor-Leste. The system is equipped with 1200 PV modules (polycrystalline silicon) using three inverters, with a total generating capacity of 250 kW, and started its operation in late 2014.

Initially, the PV system performance from 2015 to 2016 is evaluated. Data are collected from the FEST laboratory office combined with meteorological data. To obtain an accurate result of the system performance, an European standard guide to assess the performance of a PV grid connected system is used. The performance analysis result obtained through calculation of parameters used. The simulation with battery and load fluctuation results were obtained through HOMER Pro simulation tools. Finally, some solution to maintain a better system performance are presented.

This study will present to the FEST of UNTL and hopefully could help in future designing, operating and maintenance of new grid connected systems.

Resumo

A crescente demanda de energia nos países em desenvolvimento levantou a questão da segurança energética. Isso tornou fundamental o desenvolvimento do potencial dos recursos renováveis inexplorados nos anos antecedentes, nos quais se destaca a energia solar. O seu crescente interesse e implementação levaram a um aumento do aprimoramento tecnológico desses sistemas, o que permitiu uma redução significativa de custos e um aumento da sua capacidade económica. O crescimento da tecnologia fotovoltaica para a geração de energia é um dos mais elevados no campo das energias renováveis e esta tendência deverá continuar a crescer nos próximos anos. À medida que a energia fotovoltaica se torna mais acessível, os seus usos para aplicações conectadas à rede estão aumentando. A transição para o fotovoltaico como tecnologia competitiva será necessária na maioria dos mercados de energia. Esse processo terá que ser complementado por uma avaliação realística do sistema instalado, com informações credíveis e recomendações confiáveis.

Neste estudo, apresenta-se a avaliação do desempenho de um sistema micro, conectado à rede, seguindo-se a simulação do sistema ligado a baterias com a uma análise de sensibilidade das flutuações de carga. Este sistema fotovoltaico está instalado nos edifícios da Faculdade de Engenharia, Ciência e Tecnologia (FECT) da Universidade Nacional Timor Lorosa´e (UNTL), localizada em Díli, Timor-Leste. O sistema está equipado com 1200 módulos fotovoltaicos (silício policristalino) utilizando três inversores, com capacidade total de geração de 250 kW, e iniciou as suas operações no final de 2014.

Inicialmente, o desempenho do sistema fotovoltaico nos anos de 2015 e de 2016 foi avaliado. Os dados foram coletados no escritório do laboratório do FECT e combinados com dados meteorológicos. Para obter um resultado certo do desempenho do sistema, foi utilizado um guia padrão europeu na avaliação do desempenho do sistema conectado à rede. O resultado da análise de desempenho foi obtido através do cálculo dos parâmetros utilizados. Para a simulação com bateria e avaliação das flutuações de carga usaram-se as ferramentas de simulação do HOMER Pro. Consequentemente, algumas soluções para manter um melhor desempenho do sistema são apresentadas.

Este estudo será apresentado ao FECT da UNTL e espera-se que poderá ajudar no projeto, operação e manutenção de futuro sistemas conectados à rede.

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List of Abbreviations

AC = Alternating Current

BPP = Betano Power Plant

CF = Capacity Factor

DC = Direct Current

E_{AC} = AC Energy

E_{SC} = DC Energy

E_c = Energy Consumption

E_e = Energy Export

E_i = Energy Import

E_P = Energy Production

EDTL = Eletricidade de Timor-Leste

FEST = Faculty of Engineering, Science and Technology

FIT = Feed-in-tariff

H_i = Incident Energy

HPP = Hera Power Plant

IEA = International Energy Agency

INV = Inverter

L_T = Total Losses

NOCT = Nominal Operating Cells Temperature

PR = Performance Ratio

PV = Photovoltaic

SOC = State of Charge

T_a = Ambient Temperature

UNDP = United Nation Development Program

V_{OC} = Voltage Open Circuits

UNTL = Universidade Nacional Timor Lorossa'e

Y_A = Array Yield

Y_F = Final Yield

Y_R = Reference Yield

Nomenclature

A_{PV}:	Area of the PV Module (m^2)
CF_A:	Annual Capacity Factor (%)
E_{AC}:	Energy Produced by the PV System (kWh)
E_c:	Energy Consumption (kWh)
E_{DC}:	DC Energy Input of the Inverter (kWh)
E_e:	Energy Export to the Grid (kWh)
E_g:	Energy Generation of the PV System(kWh)
E_i:	Energy Import from the Grid (kWh)
E_{In}:	Energy Input of the Inverter (kWh)
E_{out}:	Energy Output of the Inverter (kWh)
Ep: E	nergy Produces by the PV Modules (kWh)
G_O:	Array Reference Irradiance (kW/m^2)
$H_{I:}$	Incident Energy in the Array Plane ($kWh/m^2/day$)
L_T:	Total Energy Losses (kWh/(kWp.d)
P_O:	Rated Power Output of the Installed Array (kW)
$P_{maxG,STC:}$	PV Array Rated Power at Standard Condition Test (STC) (kW)
PR:	Performance Ratio (%)
Ta:	Ambient Temperature (^0C)
Y_F:	Final Yield (kWh/(kWp.d)
Y_R:	Reference Yield (kWh/(kWp.d)
$\eta_{PV,A}$:	Efficiency of the PV Array (%)
η_{Inv} :	Inverter Efficiency (%)
η_{Sys} :	System Efficiency (%)

1. Introduction

1.1 Background

Eelectricity became one of the most useful energy forms used worldwide. Increasing electricity demand led to the increase of the power generating capacity. Power generating based in fossil fuels is still dominant in the development of power plants. Even though, it can also cause environmental problem such as CO_2 emissions. Thus, it is necessary to increase the use of renewable energy in the development of power generation system (Blaabjerg et al., 2006). According to the International Energy Agency (2018), global electricity generating capacity has increased by 3.1%, or about 780 TWh, in 2017. Renewable electricity shares about 25% of overall generation. Despite solar PV and wind generation, hydro power is the largest source of renewables-based power production with a major allocation of 65% in overall renewables output. Large solar based power plant projects in China, Japan, USA, Germany, and India are still grown. Many big solar projects in those countries have been commissioned, for instance, 579 MW Solar Star project in the USA and 850 MW Longyangxing Dam Solar Park project in Cina (Chatterjee et al., 2018).

The scenario of electricity generation strongly differs from one country to another. Power generation in Timor-Leste is heavily based on diesel fuels. It is comprised of two main power plants, namely Hera Power Plant (HPP) and Betano Power Plant (BPP). The capacity of HPP and BPP are 120 MW and 130 MW, respectively. The national transmission grid is 150 kVA and has been connected throughout the country through ten substations to power community houses. Although the electricity is available for 24 hours across the country, the government has set its renewable energy policy to encourage the integration of renewable energy sources such as solar energy, wind energy and hydro power to the network, to reduce its energetic dependency and minimize fossil fuels imports (UNDP Timor-Leste report, 2014).

Efforts in addressing renewable electricity goals are ongoing through national projects. There were some renewable electricity projects that had been implemented in the scope of an incentive program named Introduction of Clean Energy by Solar Electricity Generation System project. Within this project, the first solar power plant with the capacity of 250 kW was built in 2014. This solar PV grid-connected system is located in the Faculty of Engineering, Science, and

Technology (FEST) of the Universidade Nacional Timor Lorosa'e (UNTL) campus. In addition to this PV grid-connected system, small size (5 x 7 kW) PV Stand-alone systems were also built in five public schools in different locations (Timor-Leste Government, Ministry of Education. 2014). The introduction of these advanced renewable energy technologies provides those institutions with energy and reduces the negative impacts of using fossil fuels to generate electricity. In addition to the reduction on fossil fuels consumption, it offers those institutions knowledge on sustainable energy options and demonstrates how these technologies can be implemented in the local context. Moreover, it provides those institutions with a clear evidence on how far these technologies can address their electricity problems.

Beyond solar projects, a mini hydropower project was also built. The Norwegian Government, through its cooperation program with the Timor-Leste Government, had installed a micro hydroelectric with the capacity of 326 kW. This system was integrated to the main grid to power communities' households in the Suco of Gariuai, Baucau District. The Gariuai Mini Hydroelectric Power project is the first mini hydropower station in the country. Electricity produced by this system is counted about 1.5 GWh annually (Hoeiseth and Klassius, 2007). The implementation of this project has positive impacts on local communities. It improves the quality of life in individual household. Local people were directly involved in the construction of the micro hydropower station. Beyond the job opportunities, the application of the hydropower station had responded to the local electricity demands. However, unfortunately, the system is now disconnected from the main grid because it has been broken. This occurred because of a natural disaster happened in 2012. The authority faces difficult in fixing the system due to lack of human resources and financial support, such as cost for replacing some damaged parts. Local communities are now having access to the electricity from the main grid because the government has expanded power distribution line to this community (Timor-Leste Government, Office of EDTL. 2018).

Increasing the knowledge about the technologies used to convert renewable sources of energy into electricity is crucial for the development of the sector in Timor-Leste and can contribute positively to economic growth and welfare of the population.

1.2 Objectives

It is undeniable that solar energy available at a specific site is not same throughout the year. It varies also from one location to the other. Apart from this, seasonal variation also affects the amount of solar radiation reaching the surface of the earth. This solar radiation would directly affect the amount of energy generated from the power plants. Likewise, power production from solar PV system depends on the quality of components used in the system. In order to maintain continuous operation of a solar PV plant, it is important to carry out an effective study on the system operating characteristics under the weather conditions, and components used in the installed system. Only in this way the performance of the installations can be improved and the penetration of the technologies can be increased.

1.2.1 General Objectives

The general objectives of this dissertation are to obtain data on the generation of electric energy from the solar PV plant installed on campus of FEST-UNTL and perform an analysis to see whether the system installed is performing satisfactorily. Furthermore, storage, by means of batteries, is a potential improvement that will also be carried out. The motivation for this exercise is the fact that the energy not consumed in the faculty buildings during day time is fed into the grid but not paid, whereas the energy consumed during night time is paid by the faculty. In addition to this, an analysis based on the data obtained will also be carried out to see the impact of the available system capacity with the increasing demand in the future.

1.2.2 Specific Objectives

The learning objectives that specifically can be achieved from this dissertation process are to:

- Qualitatively evaluate the performance of the system by using the performance standard guide developed by the International Energy Agency (IEA);
- Quantify energy produced, through monitoring data collection system, from the system installed in the FEST of UNTL at Hera Campus;
- Quantify energy consumed of the FEST from the system;
- Provide a clear information on how this system can help FEST in reducing their energy bills;
- Discuss the need to expand the system, installing more generating capacity;

- Ascertain the prospect for using batteries in responds to the future increase of FEST energy demand;
- Identify other renewable sources, such as wind energy, to complement the system.

1.3 Structure of the Dissertation

This dissertation is structured as follows:

Chapter 1 presents an introduction, which explains the background of the power generating in Timor-Leste, the objectives of this study, and the specific objectives that can achieved.

Chapter 2 provides a state of the art, which presents a literature review on PV grid-connected system performance analysis. Some examples of PV grid-connected system performance have been investigated and are discussed. The PV technologies, system types, and evolution of the PV costs are also assessed.

Chapter 3 presents the energy situation in Timor-Leste and the potential for the use of renewable energy resources. Electrical system characteristics and the potential of renewable energy sources available in the country are explained. The environmental impact from those resources will be briefly discussed.

Chapter 4 presents the methods that are used to answer to the specific questions described in this dissertation. The system description and the parameters that are used to analyze the performance of the Hera PV plant are explained. The input parameters for the simulation of the system with battery, and the sensitivity analysis of load fluctuation are presented.

Chapter 5 presents the results and discussion. Energy generated and supplied by the system is discussed. The performance analysis results based on the parameters provided are explained and discussed, and the simulation of batteries attached to the system, and the sensitivity analysis of load fluctuation are explained.

Chapter 6 sets out the final conclusions of all the work, summarizes the findings and the answers to key questions in this dissertation.

2. State of Art

2.1 Literature Review

Literature review on the previous works related to the performance analysis of a solar PV grid-connected systems is done in this section.

Perez et al. (2007) presented the performance analysis of the 200 kWp PV grid-connected installation installed in Jaén University Campus, Spain. The PV installation consists of four systems with different architecture and configuration. System 1 and 2 were installed in the university parking area, system 3 was installed in the university buildings where the inverters, the data monitoring system and the safety and protection system were also located. Meanwhile, the PV system 4 was integrated in the south facade of an existing building close to the system 3. All systems were completely integrated at campus buildings. This study showed the system has worked effectively. Also, the authors found that PV systems 1 and 3 have shown good performance whereas systems 2 and 4 indicate a reduction of performance ratio. In order to increase the performance ratio of the system, the defective part of the installation which was responsible for the diminution of PR was replaced.

Karki et al. (2012) conducted a comparative study of performance of PV grid-connected system in two different cities, Kathmandu and Berlin. Authors analyzed the performance using PVSYST software. A 60 kWp system was simulated with the same parameters in both cities. The amount of energy produced from PV array and the energy fed into the grid were also investigated. Apart from the energy produced, various energy losses through the system were also analyzed.

Some studies were carried out by Kandasamy et al. (2013) on a 1 MWp grid connected solar power plant at four different cities in India. Authors conducted a detailed study on the solar potential assessment for those sites. PV SYST software was used to analyze the system performance. A comprehensive evaluation of energy produced, efficiency of PV array, system performance ratio and other cost parameters were executed.

Sharma and Chandel (2013) conducted a detailed study on a PV grid interactive system installed at Khatkar-Kalan, India. In this study, authors analyzed the performance of a 190 kWp PV power plant by using two different methods, PV SYST software and practical measurements. The PV system capacity factor, the average performance ratio, and the system efficiency were elaborated. In addition, total estimated system losses due to temperature, solar radiation, array mismatch, module quality, inverter, and ohmic wiring were also investigated.

Kazem et al. (2014) designed, implemented, and evaluated a 1.4 kW grid-connected PV system in Sohar, Oman. Two parameters were used to evaluate the system, the capacity factor and the yield factor. The cost of energy as well as simple payback period were also calculated. The result shown the capacity factor and the yield factor for the proposed system were 21% and 1875kWh/kWp/year, respectively. In terms of the economical evaluation factor, it was found that the cost of generating energy from the PV system was lower compared to the subsidized price of energy generated with fossil fuel. The cost of energy generated by the system was about 0.045 USD/kWh with the simple payback period of about 11 years.

Kumar et al. (2014) carried out a study on a roof top 20 kWp PV grid connected system in a manufacturing industry in India. In this study, the operational behavior, economic calculation, and some significant features of the installation were emphasized. Moreover, important aspects of PV plant installation such as the viability of locality in terms of geographical data, solar panel inclination design and interfacing aspects of PV system with network were also discussed. The detail of the outcomes obtained from the study such as monthly energy generation, maintenance aspects, performance ratio, capacity factor, economic scrutiny of the system were also elaborated.

Kumar and Shudakar (2015) carried out a performance study of a 10 MWp grid connected solar photovoltaic power plant installed at Ramagundam, India. In this study, solar PV plant design aspects along with its annual performance were developed. Various system losses due to temperature, internal network, inverter and ohmic wiring were examined. Apart from these losses, the system performance ratio and the energy final yield were also calculated. The performance results were then compared with the simulated values attained from the PV SYST and PV-GIS software. The results have shown the final yield of the plant varying from 1.96 to 1.07 h/d, and annual performance ratio of 86.12%. The annual amount of energy generated from the plant was about 15.7982 GWh.

Similar study was carried out by Attari et al. (2016) on a 5 kWp PV grid-connected system installed in Tangier of Morocco. The system was installed in top of a government building and made up of 20 modules of 250 Wp. The experimental data during the periods of 2015 was recorded based on the real time surveillance. In this study, energy output of the system, final yield, modules temperature, plant efficiency, and system performance ratio were assessed. Various power losses were also investigated. The result of the study have shown, the final yield range between 1.96 to 6.42 kWh/kWp, annual capacity factor is 14.83%, plant efficiency is 11.99%, and the performance ratio varying from 58% to 98% depending on the irradiation levels. In addition, the plant supplied energy to the grid with 6.4113 MWh during the year 2015.

Shukla et al. (2016) showed the simulated performance of a 110 kWp solar rooftop photovoltaic plant connected to distribution network for a residential hostel building at Manit, India. The authors analyzed the viability of solar PV system at the given location. In this study, four types of modules were used in the simulation to examine system performance ratio and energy yield. In addition, the Solar GIS PV Planner software was used to evaluate the performance of the system. Global in-plane radiation, shading effects, angular reflection at the surface of the arrays, system losses, and power conditioner performance were evaluated. The study result have shown that, the performance ratio ranged between 70% to 88%, and the energy yield ranged from 2.67 kWh/kWp to 3.36 kWh/kWp. Furthermore, among the four types of modules examined, a-Si and CdTe PV system have performance ratios greater than 75%.

Allouhi et al. (2016) investigated the performance analysis, economic and environmental evaluation of two 2 kWp solar power plant installed in High School of Technology of Meknes, Morocco. In this study, poly-Si module and mono-Si module were used, and the simulations were carried out using PVSYST software. The meteorological data for the site were taken from METEONORM database. System capacity factor, final yield, and system efficiency for both installed technologies were calculated. From the simulated results, the authors found that PV installation using Poly-Si technology has a higher performance compared to the Mono-Si technology. The average daily final yields for Poly-Si and Mono-Si were, respectively, 4.98 h/year and 4.85 h/year. Furthermore, the annual overall efficiency and annual capacity factor of the PV system were 20.52% and 12.3% respectively.

Kumar et al. (2017) analyzed a simulated performance on a 100 kWp Si-poly PV grid-connected system. The authors simulated the proposed system to evaluate the feasibility of installing that system in an educational institute. The simulated system consists of 323 Si-poly modules of 310 Wp. All modules were arranged in 17 strings and each string was made up of 19 modules connected in series. Four solar inverters of 20 kW were used to connect the system to the main network through a utility meter. The PV SYST V6.52 software was used in the simulation. The effective energy output, energy supplied to the grid, and performance ratio of the system were evaluated. In addition, the system losses were also processed. The simulation result shown, the system produces 165.38 MWh/year, and 161.6 MWh/year was injected to the grid. Moreover, the annual performance ratio was about 80%.

2.2 Solar PV Technology

Among the clean energy resources, the conversion of the solar radiation into electricity by PV devices is a reliable choice to meet the global energy demand. Solar PV technology is one among other technologies to convert renewable resources which have a potential to offer clean energy, affordable, and reliable electricity system in the future (Tyag et al., 2013). Despite the benefits of this clean and unlimited resource, a higher efficiency to cost ratio is necessary for the installed PV devices to make them competitive with the conventional energy resources. Observing this fact, governments all over the world are inspired to develop and deploy solar PV technology. Sampaio and Gonzales (2017) reported that, today, there is a wide variety of PV cells technology available in the market that utilize different type of materials and it will increase in the future. PV cell technologies are normally classified in three generations, based on the raw material used and on the level of commercial maturity. The three generations are as follows:

- First generation PV systems, fully commercial, use the wafer-base crystalline silicon (c-Si) technology, both in its simple crystalline form (sc-Si) as well as in the multi-crystalline form (mc-Si).
- Second generation PV systems, in their early market deployment phase, are based on thin film photovoltaic technologies and generally include three main families: (1) Amorphous silicon (a-Si) and micro amorphous silicon (*a-Si /μc- Si*); (2) cadmium telluride (*CdTe*); and (3) copper indium selenide (*CIS*) and copper, indium gallium dieseline (CIGS).
- Third generation PV systems involve organic photovoltaics cells and concentrating PV (*CPV*) cell technologies that are still in demonstration or have not been widely marketed and new concepts in development.

Goetzberger et al. (2002) reported that there are some requirements for a solar cell material to be considered ideal: (1) band gap between 1.1 and 1.7 eV, because the smaller the gap, the easier it is to promote an electron from one band to the other and thereby increase the conduction of this material; (2) direct band structure; (3) consisting of readily available materials, non-toxic; (4) easy fabrication technique, suitable for large production volumes; (5) good photovoltaic conversion efficiency; (6) long-term stability.

2.3 Classification of PV Solar Cells

2.3.1 Crystalline Silicon (c-Si)

Silicon is one of the leading materials in solar PV technology. The first-generation PV modules was manufactured from crystalline structure of silicon. Crystalline silicon has been the major material for the manufacture of solar cells for the past 20 years and it is expected to continue. This is based on the inherent benefits of silicon as a semiconductor and on the major industry that has been built to manufacture silicon devices (Bruton, 2002). The c-Si has two types that are available in the market, *polycrystalline* and *monocrystalline*.

Polycrystalline

Polycrystalline silicon usage is growing more rapidly than monocrystalline. This is because polycrystalline silicon has lower capital cost for wafer production, higher silicon utilization and square wafer, which give a higher packing density in the module. Polycrystalline has lower cell efficiency. A study conducted by Zhao et al. (1998) reported that the honeycomb textured polycrystalline solar cell efficiency was 19.8%. A polycrystalline silicon module can be viewed in figure 1.

Figure 1. Polycrystalline PV module.

Monocrystalline

In contrast, monocrystalline wafer is expensive to produce but gives a higher efficient solar cell. A study conducted by Zhao et al. (1998) reported that the honeycomb textured monocrystalline solar cell efficiency was 24.4%. However, its module efficiency was lower. A monocrystalline silicon module can be viewed in figure 2.

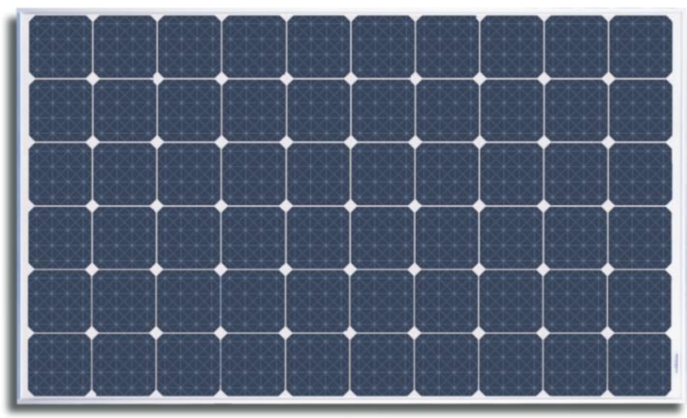

Figure 2. Monocrystalline PV module.

Although the percentage of polycrystalline silicon solar cells production is likely to rise, a market for high-efficiency monocrystalline silicon solar cells will always exist. High efficiency is important in applications where space is limited, higher labor cost, and the amount of solar radiation is relatively low (Bruton, 2002). Zhao et al. (2001) reported that, passivated emitter, rear totally diffused (PERT) and passivated emitter, rear locally diffused (PERL) cells with a high-efficiency have been fabricated on magnetically confined Czochralski (MCZ) silicon wafers. A 24.5% energy conversion efficiency based on PERT MCZ had demonstrated and it was confirmed by the Sandia National Laboratories under the standard test condition of $100 mW/cm^2$ global AM1.5 spectrum at 25^oC.

Crystalline silicon cells in mass production have considerably lower efficiency. For polycrystalline with large grains, the efficiency is in the range of 15 to 17 % and for monocrystalline one in the range of 17 to 19 %. However, the cost per Watt peak of the PV system is too high to compete with the traditional energy sources, fossil fuels. Therefore, the efficiency of cells should increase, and the areal cost of the PV system should decrease. The silicon solar cells produced today have a potential to increase the efficiency and to reduce the price, but there is a limit of the cost which could be too high. To overcome this limit, the new concepts of solar cells of third generation photovoltaics are developed (Green, 2006).

2.3.2 Thin-film Technology

Thin-film is an alternative technology, which uses less or no silicon in the manufacturing process. Today, an extensive variety of TF-Si PV devices have been developed on the commercial scale, including single-junction amorphous silicon (a-Si), dual junction a-Si/a-Si, tandem-junction microcrystalline silicon, amorphous silicon known as “micro-morph”, and triple-junction germanium-doped amorphous silicon (a-Si/a-SiGe/a-SiGe) (Gul et al., 2016). Some types of thing film technology are described in this sub section.

Amorphous Silicon (a-Si)

Amorphous silicon is a non-crystalline allotropic form of silicon and the most commonly developed. It is well known among thin film technology, but it is prone to degradation. Some of the varieties of a-Si are amorphous silicon carbide (a-SiC), amorphous silicon germanium (a-SiGe), microcrystalline silicon (μ -Si) and amorphous silicon-nitride (a-SiN) (Parida et al., 2011). The first a-Si publications related to the manufacture of solar cells appeared after the 1960s, and it was initially reported by Carlson in 1976. An a-Si occurred in the market in 1981 (Sampaio and Gonzales, 2017). Amorphous silicon module can be seen in figure 3.

Figure 3. An amorphous silicon PV module.

An a-Si cell is used for single-junction cells but tend to give efficiencies of only about 6% or less because of high defect concentrations related with the lack of crystallinity (Lechner and Schade, 2002). Research was continuing to find ways to reduce this effect during the last two decades. The highest confirmed stable efficiency for an a-Si cell was about 9.8% (Green et al., 2011). The high expectation of this material was contained by the relatively low efficiency obtained so far and by the initial degradation induced by light. This is the reason why a-Si has not been able to reach a significant share in the PV global markets.

Cadmium Telluride (CdTe) or Cadmium Sulphide (CdS)

Cadmium telluride solar cells are formed from cadmium and tellurium. The CdTe has been known to have the ideal band gap of 1.45 eV with a high coefficient of absorption of the solar spectrum being one of the most promising photovoltaic materials for thin film cells. However, the toxicity of cadmium (Cd) and environmental issues related to the use of this material pose a problem for this technology. Therefore, First Solar, one of the world's largest manufacturers of photovoltaic solar modules, has launched a recycling program for deactivated PV cells, extremely popular in the field of thin films because of the efficiency of its process, which has the capacity to reduce the cost of production to make this technology more competitive. The other potential problem is the availability of Te, which can lead to scarcity of raw materials, thus affecting the cost of the modules (Sampaio and Gonzales, 2017). There were several remarkable studies conducted previously on CdTe cells. Amin et al. (2001) found the CdTe efficiency of 10.6% and 11.2% was obtained on a thin film of 0.55 and 1 mm thick, respectively. In addition, CdTe on plastic foil with an efficiency of 11.4% is reported by Upadhayaya et al. (2007). In general, 15% to 16% cell efficiency has been obtained by Ferekides and Britt (1994), and Wu et al. (2001). In July 2011, First Solar company sets the world record of 17.3% cell efficiency, which was confirmed by the National Renewable Energy Laboratory, NREL (National Renewable Energy Laboratory, 2015).

Copper Indium Gallium Selenide (CIGS) or Copper Indium Selenide (CIS)

Copper and indium diselenide ($CuInSe_2$) or indium copper selenide (CIS), as is sometimes known, and copper-indium-gallium selenide (CIGS) are photovoltaic devices containing semiconductor elements of groups I, III and VI of the periodic table which are Beneficial because of their high optical absorption coefficients and their electrical characteristics that allow the adjustment of the device (Hosenuzzaman et al., 2015). Some of the major challenges of these technologies have limited ability to expand the process of high yield and low cost, degradation under wet conditions, as it promotes changes in the properties of the material and the shortage of Indian in nature (Chaar et al., 2011). Repins et al (2008) reported that, the CIGS cell efficiency in 2006 was 20% and about 13% for module (Powalla, 2006). In the late of 2013, Siva Power has reported highest cell efficiency of 18.8% which was confirmed by the NREL (Osborne, 2014).

Gallium Arsenide

Gallium arsenide (GaAs) is a compound semiconductor form of Gallium (Ga) and Arsenide (As). GaAs has a similar structure as silicon cells with high efficiency and less thickness, and it is lighter as compared to monocrystalline and multi-crystalline silicon cells (Iles, 2001). Its energy band gap is 1.43 eV (Streetman and Banerjee, 2005) which can be improved by alloying it with Aluminium (Al), Antimony (Sb), Lead (Pb), which in turn will form a multi-junction device (Satyen, 1998). The Spire Corporation has manufactured the most efficient triple-junction, GaAs cell, with an efficiency of 42.3% (Osborne, 2010). The Sharp company has been pursuing research and development of a triple-junction compound solar cell that achieves high conversion efficiency by stacking three photo-absorption layers. In 2009, Sharp succeeded in improving cell conversion efficiency to 35.8% based on proprietary technology that enabled efficient fabrication of a stacked triple-layer structure with indium gallium arsenide (InGaAs) as the bottom layer. In 2011, conversion efficiency of 36.9% was achieved, at the research level, for a triple-junction compound solar cell (Sharp, 2011). This technology is still under research and, hence, there are fewer commercial modules available in market.

2.3.3 Organic Photovoltaic Cells

Organic photovoltaic cells offer the long-term potential of achieving the goal of a PV technology that is economically viable for large-scale power generation, since organic semiconductors are a less expensive alternative to inorganic semiconductors, such as silicon. Furthermore, organic molecules can be processed by simpler techniques that are not suitable for crystalline inorganic semiconductors. Almost all organic solar cells have a flat layered structure, wherein the light absorbing layer is sandwiched between two different electrodes. One of the electrodes has to be semi-transparent, the indium tin oxide (ITO) is normally used, however a thin layer of metal can also be used. Calcium, magnesium, gold and aluminum can also be used as electrodes, the latter being the most used (Benanti and Venkataramen, 2006).

Research on organic solar cells aims to increase the conversion efficiency of solar energy, since the total energy output of a solar cell is equal to the product of its efficiency and lifetime. Therefore, the stability which is directly related to the lifetime is an important property for this type of cell, since it impacts the value of an energy production system based on this technology. Over the past few years, many aspects of organic solar cells have been extensively studied, including the synthesis and application of new materials, physical process modeling, large-scale manufacturing, and improved stability (Cao et al., 2014). However, the research and development of organic solar cells still has a long way to go to compete with inorganic solar cells (Benanti and Venkataramen, 2006).

2.4 PV System Types

Solar PV system can be designed across a wide range of complexity, from a very simple system which simply designed to feed a load, to a system with a high degree of complexity such as large PV plants. A typical stand-alone PV system consists of four basic elements; PV modules, charge controller, the inverter, and the battery when required. One of these systems is sketched in figure 4.

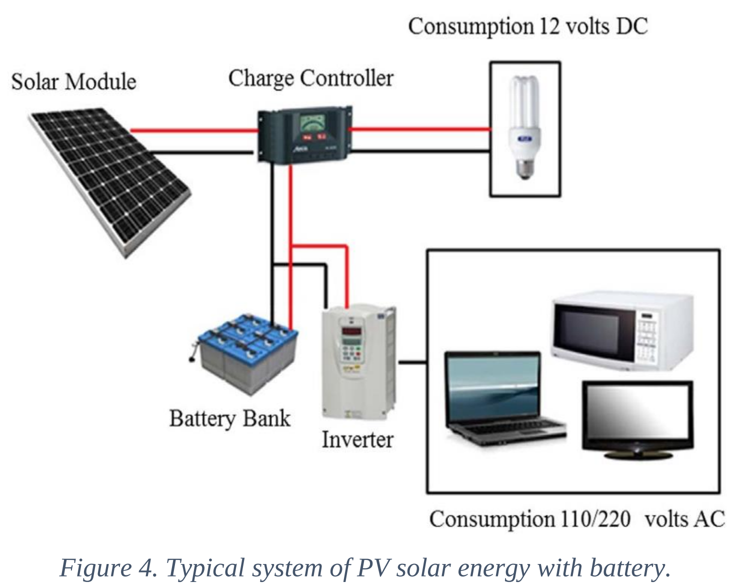

Figure 4. Typical system of PV solar energy with battery.

The PV module consists of PV cells, which convert directly solar energy into DC electricity. These surfaces have no moving parts to wear out and work without the use of fuel, without vibrations, no noise and not harming the environment (Lan and Li, 2014). As for the charge controller, it has the function to preserve the batteries from being overcharged completely and increasing battery useful life. The inverter, in turn, is responsible for converting the power generated by the PV modules into alternate current (AC). Batteries are used in a PV system to store the excess energy generated by the modules to be utilized at night or on days with low sunshine (Hosenuzzaman et al., 2015). There are more complex of PV systems such as stand-alone systems, on-grid connected systems and hybrid systems.

2.4.1 Stand-alone PV Systems

Stand-alone PV systems are not connected to the local grid. They are beneficial in remote areas that are isolated from the power distribution network, and are mainly used for small self-consumption. For remote areas where the AC main grid is not accessible, the stand-alone PV system provides energy to local users behaving as an AC voltage source. Because of the unpredicted nature of the PV source, a chargeable battery or backup supply is necessary in order to store the excess energy during the high solar irradiation period and supply to the load when the PV energy is not available. Fluctuating voltage and power are of major concern in the PV stand-alone systems. To address these issues, a control strategy for voltage control using voltage source inverter in the voltage control mode is used. The block diagram of a common stand-alone PV system is illustrated in figure 5.

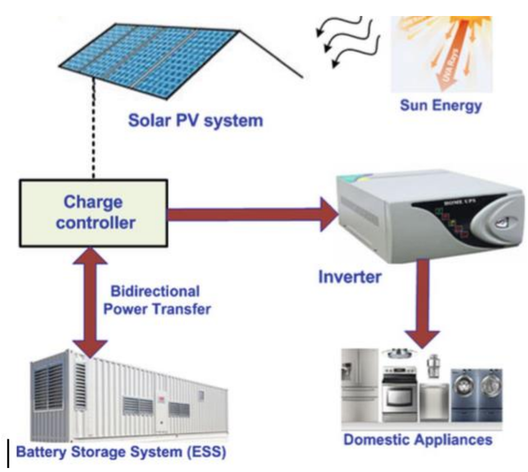

Figure 5. Block diagram of an Off-grid PV systems.

The standard voltage level of such operations is normally in the range of 220-250 AC. Consequently, the voltage level of the DC link of the DC-AC inverter that feeds these loads needs to be maintained around 360-400 V. The voltage levels of the PV modules that are available commercially are generally in the range of 12-15 V. Therefore, to form a DC bus of around 360-400 V, several PV modules are to be connected in series to form PV string (Walker and Sernia, 2004). Variable DC link voltage across the inverter can affect the sensitive load supplied. As there are no grid lines in an off-grid PV system, the output voltage has to be controlled in terms of amplitude and frequency. The off-grid PV system control is featured with a frequency and output voltage controller that is capable of handling variable loads.

2.4.2 Grid-connected PV Systems

Grid-connected PV systems are directly connected to the distribution grid for the supply of surplus energy into the grid after self-consumption. These types of PV plants are useful for high power generation and efficient use of solar power. In addition to that, it also uses in the residential or institution with the objectives of reducing their electricity bills and promoting clean energy. In grid-connected PV systems batteries are not needed, since all power generated by the PV plant is uploaded to the grid for direct transmission, distribution and consumption. Hence, the generated PV power reduces the use of other energy sources feeding the grid such as fossil fuels. Since grid-connected system do not need batteries, they are more cost effective and require less maintenance and reinvestment as off-grid connected PV system do. The grid generally refers to the power distribution system, which receives its input power from substation at 440V and 220-250V single-phase AC, at 50 Hz. Individual consumers can utilize the power in the range of 10-15 kW (Oriti and Julian, 2011). The diagram of a PV grid-connected system is shown in figure 6.

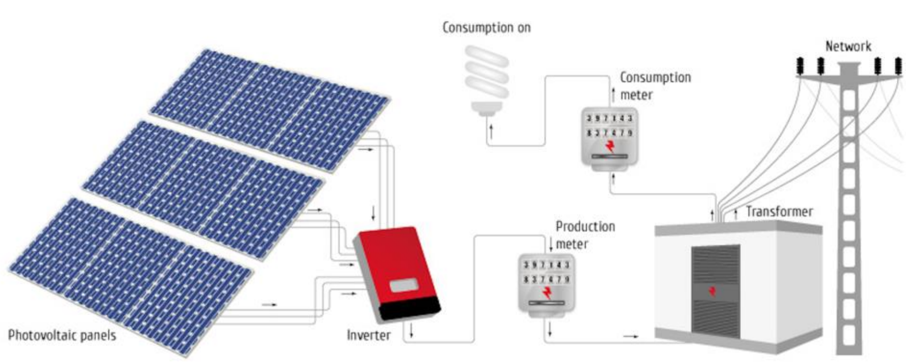

Figure 6. The diagram of PV grid-connected systems.

The main components in a PV grid-connected system are the inverter and the modules. The inverter converts the available DC power from the PV array into the usable AC power consistent with voltage and power quality requirements of the grid utility. A bidirectional interface is made between the PV system AC output terminals and the grid utility network. This enables the PV system to supply power to the local loads of feed to the grid, when PV power is greater than load demand power. At night, or during high load demands, the power required by load is greater than the PV power generated. The excess power required by the load is received from the grid utility. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed into the grid when the grid is down for service or repair (Oriti and Julian, 2011).

2.5 Evolution of the PV Costs

Costs of manufacturing of PV module and the price of the PV module have decreased significantly for decades. The first considerable reduction in PV module costs happened in the middle of 1970s, when PV moved from space to terrestrial applications. This revolution allowed for reduced demand for device quality and reliability, greater standardization and increased market competition (Maycock, 2011). This reduction in costs was caused by a decrease in c-Si module prices from $90 per watt-peak in 1968 to a $15 per watt-peak in 1978. The decline of c-Si costs continued over the periods, and improved device efficiency and manufacturing scale were judged to be the main cost reduction drivers, accounting for 30% and 40% of reduction respectively (Nemet, 2006).

Mints (2009) reported that the PV price continued to fall and stood at about $9 per watt-peak in 1987 and then increased from 1988 through 1990 as the PV modules were reduced due to a limitation in the availability of silicon wafers. PV module prices was then decreased substantially from 1991 up to 1995 because of increases in PV module manufacturing capacity and a worldwide recession that slowed PV demand. PV module prices continued to fall slightly from 1995 to 2003, which was due to increases in module capacity globally and a growing PV market. PV module prices were less than $5 per watt-peak by 2000, and even reaching a low of $3 per watt-peak in 2003.

Donne et al. (2013) reported that module prices in 2012 for the Unites State of America (USA) and Europe per watt peak were about \$2.29 and €2.17 respectively. The PV cell prices trend from 1980 to 2014 can be seen in figure 7.

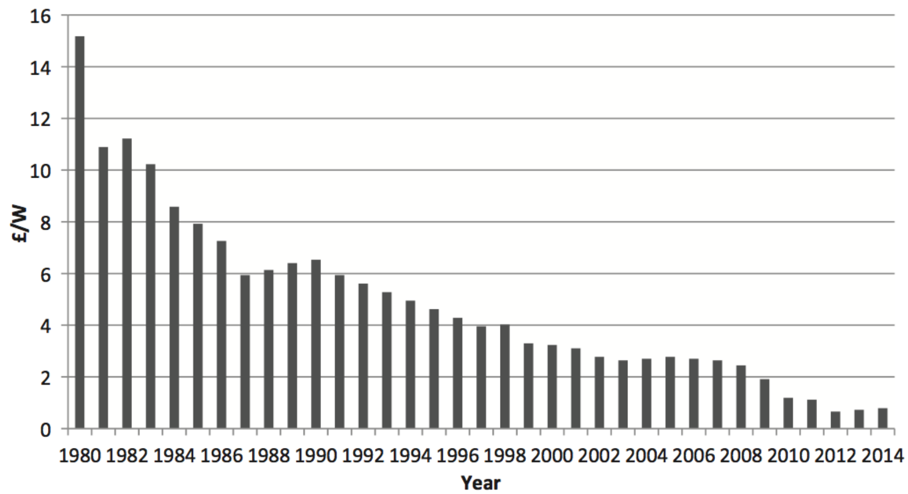

Figure 7. PV cell prices.

The cost of a complete PV system including additional equipment such as PV modules, inverter, charge controller, electrical components and mounting structure were also decreased. Factors such as increases in the amount of production, improvement in the efficiency by innovative technology, innovation in material technology, increasing lifespan of PV system, and policies for solar technology contributed to the decline of the PV costs (Green Peace International, 2011).

Gul et al. (2016) reported that the PV system costs vary from country to country and it also depends on the size of the installed systems. For example, China was the cheapest country, in terms of complete installation of PV project, and South Africa was the costliest, accounted for about £0.32 per Watt and £4.29 per Watt respectively. Considering the size of project, for 5 MW PV plants installed in the Panama was the costliest as compared to China, and India. For 50 MW projects, Chili was the most expensive as compared to India, Equador, and South Africa.

3. Energy Situation in Timor-Leste and the Potential for the Use of Renewable Energy Resources

3.1 Characteristics of Electrical System in Timor-Leste

Electricity generation in Timor-Leste is powered by engine diesel fuels. Timor-Leste imports all of its fossil fuels including diesel, gasoline, liquid petroleum gas (LPG) and kerosene from overseas. Electricity utility is owned by the state. Presently, Timor-Leste has two power generating stations, the Hera Power Plant (HPP) and Betano Power Plant (BPP). The HPP is located in Dili, the capital of the country, while BPP is located in Betano. Betano is located in the north part of the Dili District. The Timor-Leste state owns these plants. The HPP can be viewed in figure 8.

Figure 8. Hera Power Plant.

HPP has a total capacity of 119 MW (7 x 17 MW), and BPP has a total capacity of 136 MW (8 x 17 MW). Both have one sub-station that rises the voltage to 150 kV, for the purpose of connection with the transmission system. Nine substations to reduce the voltage also being built in district capitals of Timor-Leste. These substations allow connection to the existing lines of 20 kV distribution. The power distribution system carries power from the substations to supply consumers.

The management of the utility and services to the consumers is responsible by the Electricidade de Timor-Leste (EDTL). EDTL is a government department under the Ministry of Public Works, Telecommunication, and Transportation. Wartsilla in a consortium with Puri Akraya Engineering Limited are now responsible for operating the power plant, and for all service and maintenance activities that ensure plant efficiency and availability. Puri Akraya Engineering Limited is an Indonesian company, Wartsilla is a Finish company and the equipment manufacturer. The operation and maintenance of national transmission system is performed by the China Nuclear Industry 22nd (CNI22). CNI22 is a Chinese company who built the transmission lines. Diesel fuels for reliable and stable operation of the power plant have been supplied by the Esperança Timor Oan Limited (ETO). ETO is a Timorese company.

Effort has been made by the government to supply power to rural consumers all around the country. At present day, some parts of rural areas still do not have access to electricity from the main grid. Households settlement and the topography of the site are two mains obstacles to extend the distribution line. The majority of households across the country have now access to the electricity for 24 hours per day. This achievement has carried a considerable and potentially increasing financial cost to the government. A substantial proportion of this cost is from the cost of the subsidization of the provision of diesel-generated electricity. This is mainly driven by the high fuel cost per unit of electricity generated and the low rate of cost recovery.

Regarding electricity generated based on renewable energy sources, the Timor-Leste government has the commitment to introduce clean energy through the deployment of the renewable energy technologies. Over the past four years, government has constructed a few small PV stand-alone systems and one PV grid-connected system. Those systems were installed in the public institutional education buildings at different locations. Hera PV grid-connected system was one of the projects. This project was built early 2014 and started its operation in November 2014. Although, the PV grid-connected system was implemented but the country does not have the feed-in-tariff (FIT) policy. Consequently, the Hera PV system owner, in this case FEST, does not get any money for the amount of power the system supplies to the electrical system. Unluckily, FEST must pay for the amount of electricity that imports from the grid.

3.2 Renewable Energy Resources Potential

Timor-Leste is a country with a great potential in the use of renewable energy resources. These renewable resources should be exploited to reduce its dependency on fossil fuels. Despite fossil fuel cost dependency reduction, it contributes to environmental and economic benefits. Renewable resources available in the country are discussed in this section.

3.2.1 Solar Resources Potential

Solar energy can be defined as the description given to any form of light energy and thermal energy obtain from the sun, and subsequent transformation of that energy into some form that can be used, either directly for water heating or such as electrical or mechanical energy (Martifer, 2010).

Solar energy potential is the highest among the various renewable energy resources in the country. Timor-Leste lies near to the equator line where length of daylight is almost constant for most of the year. Average monthly solar radiation per square meter from 2015 to 2016 for the FEST is presented in figure 9.

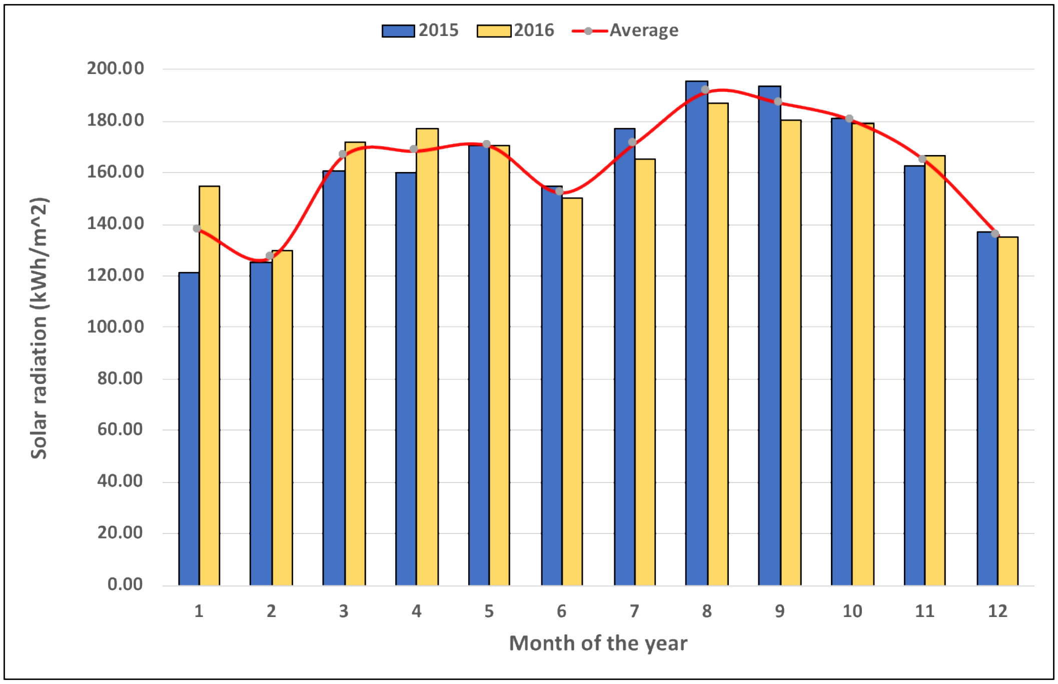

Figure 9. Monthly solar radiation data for year 2015 to 2016 for the FEST location.

As it is observed from figure 9, solar radiation reaching the plant is different in 2015 and 2016. The highest solar radiation occurred in the months of August and September, accounted for about 195.50 and 187.21 kWh/m^2, respectively. The monthly solar radiation for the other months recorded more than 120 kWh/m^2. Annual total radiation for the two periods was about 1.94 and 1.97 MWh/m^2, respectively. While the average total radiation was about 1.95 MWh/m^2.

Environmental Impact

Solar power plant projects are not emissions free at all. Emissions associated with solar PV during the manufacturing are mercury emissions, cadmium, and Green House Gas (GHG) emission. Emissions of mercury and cadmium from a solar PV system are about 0.1 g Hg/GWh and 0.02 g Cd/GWh respectively. Every 100 MW of solar power plant emits 15.6 gCO_2/kWhe (Tripathi et al., 2016). Furthermore, solar power plants require an amount of land area. The dimension of the land area depends on the capacity of the PV plants and the specific PV technology used. For a small size of PV system capacity, typically can be placed on the top of an existing building. Larger PV grid-connected system can occupy a significant area.

However, a PV plant can deliver electricity during 25 or more years, almost CO_2 emissions free, contributing in a very positive manner to the carbonization of the electricity sector.

3.2.2 Hydro Resources Potential

Beyond solar energy sources, hydro energy is one of renewable energy sources available in the country. Timor-Leste is in the tropical regions, faced with high humidity, temperature, and abundantly rainfall. Timor-Leste experiences two seasons, the rainy and the dry seasons. The rainy season starts from the month of November to the month of February. While the dry season starts from March to October. Studies conducted by the Electrification Plan of Timor-Leste and the Norwegian Cooperation shown that there was potential to install hydropower with the total capacity around 380 MW with the annual average of energy production approximately 1250 GWh. There are some places identified that have the potential for hydropower plant projects, such as in the Ira Lalaro, Gleno, Belulic, and Laclo. The most viable site, based on the minimum cost of generation projection, was the 28 MW Ira Lalaro hydro project in the eastern part of the country. The Ira Lalaro lake is able to provide water naturally for the plant. Likewise, the study also shown that, micro and mini hydro are likely to have an important role in electrification of rural villages (Martifer, 2010).

Environmental Impact.

Environmental impact associated with generating electricity from hydro energy technologies are not serious measurable because hydropower does not pollute the water and the air. Even though, the development of hydropower generation projects can arise many issues such as environmental authorization, settlement of the affected community and land asset.

On the other hand, hydropower is a mature and affordable technology that can produce electricity for many years, more than 50, being a very valuable contribution to mitigate gas emissions and other inconvenient of the use of fossil fuels. It must also be considered that water can easily be stored, that´s why hydroelectricity can provide services to the electrical system that other renewables cannot do, as a consequence of its intermittency.

3.2.3 Wind Energy Resources Potential

Wind energy is the energy coming from the wind, and wind is available almost everywhere. The velocity of the wind, wind direction and seasonal patterns can change considerably. Wind is another renewable energy source with considerable future power plant in Timor-Leste.

A previous study elaborated by the Electrification Plan of Timor-Leste and the Norwegian Cooperation shown that annual average wind speed could reach 7 m/s at certain places of the country. Furthermore, it also found that wind power was not viable in the coastal areas, but it could prove to be economically viable in the mountains and uplands. Timor-Leste wind atlas is provided in figure 10. As can be seen from the figure, the mountain areas of eastern parts of Quelicai, the southwest of Venilale, and east of Maliana have a great potential wind resources compared to the rest of the territory (Martifer, 2010). An Interesting feature of the wind resources is that the dry season, from April to October, is also the windy season. There would be a great potential for complementary with hydropower plant.

Figure 11 shows wind speed values for Dili district, the capital of Timor-Leste, during a decade, from 2005 to 2015. Data was collected from the Dili International Airport which is very close to the sea, and the terrain is flat. It is about six kilometres, to the east, from the Hera Campus. The wind speed at 3 meters from the ground was about 10 to 13.6 kilometres per hour. The highest and lowest wind speed appeared in the month of August and April, and accounted for about 3.8 and 2.8 m/s, respectively.

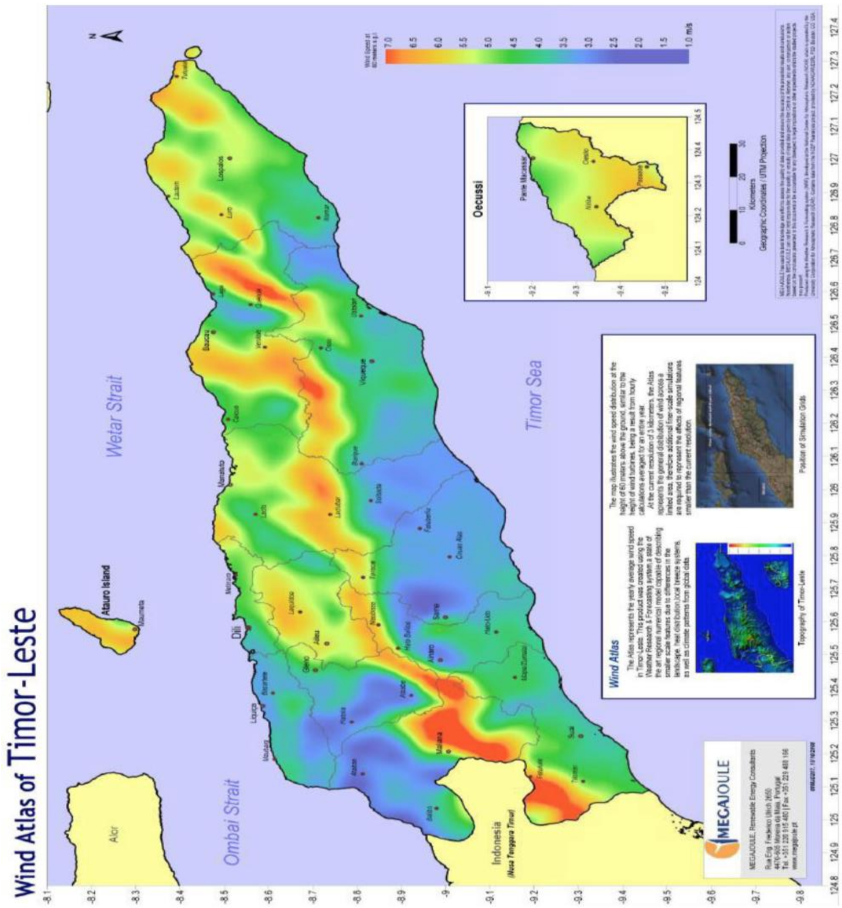

Figure 10. Timor-Leste wind atlas.

SOURCE: MARTIFER Report, p. 118.

The average wind speed was about 3.2 m/s (Timor-Leste Government, Office of Direção Nacional de Meteorologia e Geofisica, 2018). Based on the obtained values, it is definitely not a suitable site to install a wind turbine, but it can be installed a small wind turbine to combine with solar, and diesel generator to serve a small load.

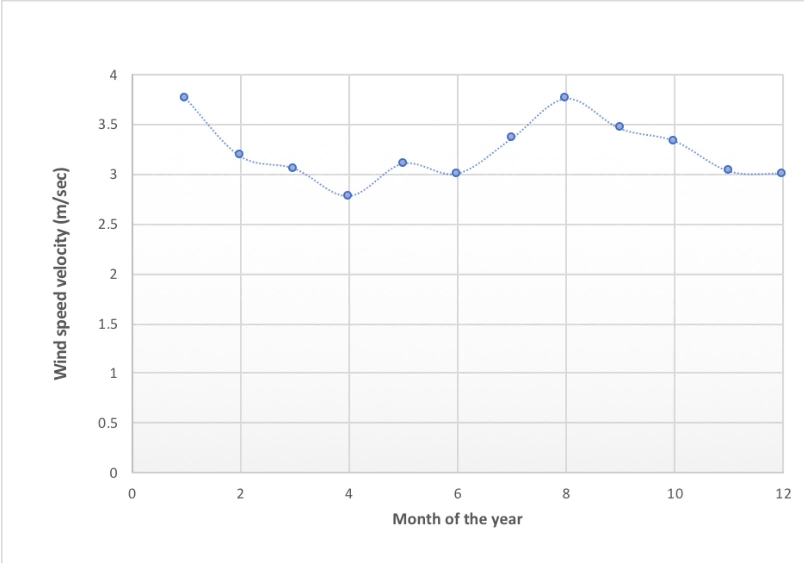

Figure 11. Average wind speed for Dili, Timor-Leste.

Environmental Impact.

The mainly concern about the impact of installing wind turbines is noise pollution. As turbine rotates, it generates aerodynamic noise, generally from the turbine blades. According to the Ministry of New and Renewable Energy (MNRE), one single turbine at a distance of 40 meters can produce noise about 50 to 60 db (2013).

However, as wind speed values in the uplands are suitable for installing a small wind turbine to serve low electrical demand in the area that are far from the main grid. Beyond that, this technology is available in the market and with various capacity that can be chose based on local energy demand levels.

3.2.4 Biomass Energy Resources Potential

A renewable resource of energy other than solar energy sources, hydropower and wind is the biomass. Biomass is conferred as the organic materials derived from vegetables, animals' dung, agriculture waste, industrial and municipal waste that can be recycled for energy production. It has been considered as renewable and carbon-neutral fuel as it has great potential of replacing as an alternative energy source that can address the global energy issues (Tripathi et al. 2016). Biomass gasification is an effective technology for decentralized electricity generation from agriculture waste and wood residues. The development of this type of technology has revealed to be relevant in terms of growth of local energy services, efficiency and economics benefits trough job creation (Chidikofan et al., 2017).

The Electrification Plan of Timor-Leste and the Norwegian Cooperation carried out a study on analyzing the feasibility of the amount of biomass residues that can be converted into useful energy in thirteen districts across the country. The study results can be viewed in table 1. As can be observed, agro-forestall residues have the highest quantities compared to the agriculture and animal residues. The study has also shown that there is a potential to generate electricity from Dili's Municipal Solid Waste (DMSW) building a solid waste recovery plant. The author estimates that a 3 MW capacity of DMSW energy recovery plant could be developed. The annual energy production was estimated about 24.1 GWh (Martifer, 2010).

Table 1. Distribution of usable biomass residues by district.

District	Agriculture	Agroforestry	Animals
	(tons/year)		
Aileu	507	236,598	1,273
Ainaro	1,990	212,986	4,883
Baucau	4,116	401,867	7,587
Bobonaro	8,840	432,679	6,347
Covalima	3,446	501,992	4,436
Dili	312	128,226	4,133
Ermera	2,147	253,375	3,147
Lautem	11,284	619,409	3,369
Liquica	735	168,593	4,562
Manatuto	3,718	741,822	3,619
Manufahi	3,217	369,768	3,042
Oecusse	2,979	161,062	5,104
Viqueque	5,897	673,106	9,134
Total	**49,186**	**4,901,484**	**60,637**

SOURCE: MARTIFER Report, p. 87

Environmental Impact

The concern about the impact of biomass generation is the sulfur oxide and nitrogen oxide emissions. Burning of biomass can also produce carbon dioxide which contributes to the GHG emissions. In addition to GHG emissions, biomass power generation uses water in the boiler for cooling system. The temperature of the water cooling coming out from the exhaust boiler is high, thus can harm plants and fish in the river or lake where the biomass power plant water is discharged.

4. Methodology

In order to answer the key questions, set out in this dissertation, three main specific tasks were carried out. The first task was to identify the location and the description of the system that will be studied. The second task was to determine the performance of the PV system including reference yield which expresses an equivalent number of hours at the reference irradiance, following with evaluating the final yield which represents the net electricity produced, divided by the rated power output. Also, load profile and power generate from the system were analyzed and the potential for expanding the system and ascertain the potential for battery storage were assessed in this section. A performance ratio was then analyzed to determine how close the PV system approaches the ideal performance under actual operating conditions. Next, energy losses and system capacity factor were evaluated. Finally, the efficiency of the system was analyzed to determine how satisfactory is the performance of the PV system components. The third task was to use HOMER Pro software to analyze the amount of energy that could be stored into a battery when it is attached to the system in order to meet the required load demand. A sensitivity analysis was also performed to comprehend the current PV system capacity in responding to the load fluctuations.

4.1 The PV System Description

The major elements of a PV grid-connected system are PV arrays, junction box, collecting box, inverters, transformer, and commercial grid. PV modules generate DC power. This DC power is the product of voltage and current. The power conditioner converts DC voltage to AC voltage. The AC output from the power conditioner is then supply to the building and main grids. For a residential use, the AC output is supplied to the buildings and the excess of the electricity is sold to the utility. In contrast, for a commercial use, the AC output of power conditioner is supplied directly to the main grid through utility meters. In PV grid-connected system, the inverter always operates in phase with the grid phase.

Figure 12. PV grid-connected system at FEST.

The Faculty of Engineering, Science, and Technology of the Universidade Nacional Timor Lorosa'e installed a 250 killowat PV Grid-connected System in 2014. The latitude and longitude of the site are $8^0$33.1'S and $125^0$39.6E, respectively. The system, as shown in figure 12, consists of 1200 PV panels, polycrystalline silicon, of 215 W arranged in 12 series-connected modules. The PV power plant consists of five arrays. Each array is made up of four panels. The system is mounted with the inclination of 10 degrees, as shown in figure 13, facing North (Office of Faculty of Engineering, Science, and Technology, 2018).

Figure 13. PV plant mounting inclination.

The technical specifications of the PV panels are provided in table 2.

Table 2. Technical specification of PV module Kyocera KD215GH-2PB.

Electrical data	
Maximum power, Pmax	215 W
Maximum power voltage, Vpm	26.6 V
Maximum power current, Ipm	8.09 A
Open circuit voltage, Voc	33.2 V
Short circuit current, Isc	8.78 A
Maximum system voltage	1000 V
Module efficiency	14.4%
Limitting reverse current (series fuse rating)	15 A
Reduction of efficiency (from 1000 W/m^2 to 20 W/m^2)	6.0%
Nominal Operating Cell Temperature,NOCT	**45_degree C**
Temperature properties: Temperature coefficient	
V_OC [V/℃](V_OC [%/℃])	-1.2*10^-1*(-0.36)
I_SC [A/℃](I_SC [%/℃])	5.27*10^3(6.0*10^-2)
P_max [W/℃](P_max [%/℃])	-9.91*10^-1(-0.46)
Standard Test Condition (STC)	**Cell temperature 25 C**
	Spectrum AM 1.5; Irradiance level 1 kW/m^2

The system is connected to two 100 kW inverters of P83BR104R model, and one 50 kW of PMC 500 model. A 350-kVA transformer is used to distribute electricity to the commercial grid and Faculty buildings.

4.2 Parameters Used in the Analysis of the Performance of the PV System

The performance parameters used in this study are the ones developed by International Energy Agency (IEA). The parameters were developed for analyze the performance of grid-connected PV system. There are several parameters used to define the overall system performance regarding the energy production, solar resource, overall system losses, performance ratio, capacity factor, PV array efficiency, and PV system efficiency. For this study, some derived parameters related to energy and performance were calculated using the monitoring data recorded.

4.2.1 Reference Yield

The reference yield (Y_R) is the ratio of the incident energy in the array plane H_I to the array reference irradiance G_O. The total daily in plane irradiation is in units of kWh/(m^2.day) and reference irradiation is equal to one kilowatt per square meter. So, the reference yield is in unit of kWh/kW/day or in hours per day. It expresses an equivalent number of hours per day during which the solar radiation would necessary to be at reference irradiance levels in order to contribute with the same incidence energy as was monitored. It can be calculated using equation (Kumar et al., 2017):

$$\boldsymbol{Y_R = \frac{H_I}{G_O}} \qquad (4.1)$$

Where:

H_I = the incident energy in the array plane (kWh/m^2/day)

G_O = array reference irradiance = 1 kW/m^2

4.2.2 Final Yield

The final yield (Y_F) of a PV system for a given period represents the net AC energy output divided by the rated power of the installed PV array at standard test condition (STC) of 1000 W/m^2 solar radiation and 25 ^{0}C cell temperature. It indicates the number of hours of operation of the array required per day at its rated capacity to equal its monitored contribution to the daily useful energy. It can be written as (Kumar and Shudakar, 2015):

$$\boldsymbol{Y_F = \frac{E_{AC}}{P_{maxG,STC}}} \qquad (4.2)$$

Where:

E_{AC} = energy produced by the PV system (kWh)

$P_{maxG,STC}$ = PV array rated power at standard condition test (STC) (kW)

4.2.3 Performance Ratio

The performance ratio (*PR*) is an indicator that normalizes the energy supplied to the grid with respect to nominal power mentioned in the specification of the PV array. Also, it indicates the overall effect of losses on a PV array´s normal output power. Its values indicate how close a PV system approaches ideal performance under actual operating circumstances. The *PR* is equal to the final yield divided by the reference yield. It can be formulated as (Kumar et al., 2017):

$$\boldsymbol{PR = \frac{Y_F}{Y_R}} \qquad (4.3)$$

Where:

Y_F = the final yield of a PV system (h/d)

Y_R = the reference yield (h/d)

4.2.4 Total Energy Losses

The total energy losses (L_T) are the PV losses due to irradiance level, array temperature, module quality, ohmic wiring, mismatch and inverter losses. It represents, numerically, the difference between the reference yield and the final yield. This can be expressed by the following equation (Attari et al., 2016):

$$\boldsymbol{L_T = Y_R - Y_F} \qquad (4.4)$$

4.2.5 Annual Capacity Factor

Annual Capacity factor (CF_A) is defined as the ratio of the real annual energy output from the plant to the amount of energy the system would produce if it worked at full rated power for 24 h/day for a year (365 days). The *CF* has a direct implication on the cost of electricity production. The annual value of the *CF* is calculated by taking cumulative sum of useful energy values at one-hour intervals using monitoring data recorded. It can be expresses as (Allouhi et al., 2016):

$$\boldsymbol{CF_A = \frac{E_{AC,Year}}{(P_o * 24 * 365)}} \qquad (4.5)$$

Where,

$E_{AC,Year}$ = annual energy produced by the PV system (kWh).

P_O = rated power output of the installed array (kW).

4.2.6 System Efficiency

The efficiencies of the PV grid-connected system components are array mean efficiency, inverter efficiency and overall system efficiency. Array mean efficiency ($\eta_{PV,A}$) describes the ratio of the annual energy output of the system to the total energy collected from the PV field (Allouhi et al., 2016). It is given by equation (4.6) in which, $E_{AC,year}$ is the energy output of the inverter, and

A_{PV} is the area of the PV modules. The inverter efficiency is given by equation (4.7) in which, E_{AC} is the energy output of the inverter, and E_{DC} is the DC energy input of the inverter considered over the reporting period. The overall system efficiency is given by equation (4.8) (Padmavathi and Daniel, 2013).

$$\eta_{PV,A} = \frac{E_{AC,Year}}{H_I * A_{PV}} \tag{4.6}$$

$$\eta_{Inv} = \frac{E_{Out}}{E_{In}} \tag{4.7}$$

$$\eta_{Sys} = \eta_{PV} * \eta_{Inv} \tag{4.8}$$

4.3 Amount of Energy Stored in the Battery when Connected to the System

Computer simulation allows optimization of different economic and engineering parameters that need to be considered in order to design and construct an energy system. It can be used to present a feasibility study of a new system, and also to analyze problems that can arise in the system´s operation. The development of a simulation software enables the designer to diagnose in order to discover the most acceptable level of a renewable energy system. HOMER Pro software is chosen in this study as it is easy to configure a system. The HOMER Pro simulation tools allow for the evaluation of a range technology combination over different constraints and sensitivity inputs to optimize energy system. This software helps to determine the best scenario that combines grid and renewable power, storage, and load management to ensure a consistent and reliable microgrid.

4.3.1 HOMER Pro Input Model

HOMER Pro simulation model is illustrated in figure 14. It can be observed that neither energy generated by the PV system and grid can directly supply energy to meet the FEST energy demands. In the case that there is any surplus of energy generated, it is fed directly to the utility grid. Some of the energy generated can be stored in the battery attached to the system. The electrical load, solar radiation and the ambient temperature input for the simulation were all values taken from the average values of data from 2015 to 2016. Simulations for each individual year were also executed in order to compare both energy production and consumption changing.

Another parameter input such as PV characteristics, inverter and grid characteristics remain unchanged.

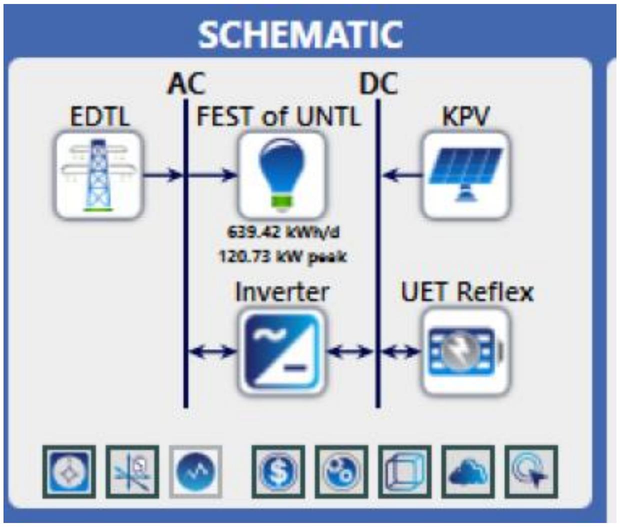

Figure 14. Simulation model for HOMER Pro.

4.3.2 Primary Load Input

To carry out the simulations and analysis, it is necessary to know the electrical load requirement of the FEST building. HOMER Pro simulation tools requires hourly load input data during 24 hours per day for each month. The average diurnal energy consumption from 2015 to 2016 including each individual year were used in this study so that the comparison in PV energy generated will be easier to show. In addition, different data from those years were used in order to see the trends and effects of different energy consumption to the simulated battery used. The electrical load input for the average monthly from 2015 to 2016 can be viewed in figure 15, while for each individual year can be seen in Annex A2 to A3.

Figure 15. Average electrical load of 2015 and 2016.

4.3.3 PV Input Characteristics

The PV parameters such as nominal operating cell temperature, module efficiency, and temperature coefficients were entered to the HOMER Pro program. These parameter values are based on the PV characteristics provide on table 2. Power input for PV array capacity is 250 kW. The derating factor which is the scaling factor that HOMER applies to the PV array power output for reduced output in real-world operating condition compared to the conditions under which the panels was rated. Use the derating factor to account for such factor as soiling of the panels, cable losses, shading, snow cover, aging and so on were assumed to be 80% (is a typical number) and the ground reflectance was set to 20%. PV characteristics used for the simulation are shown in figure 16.

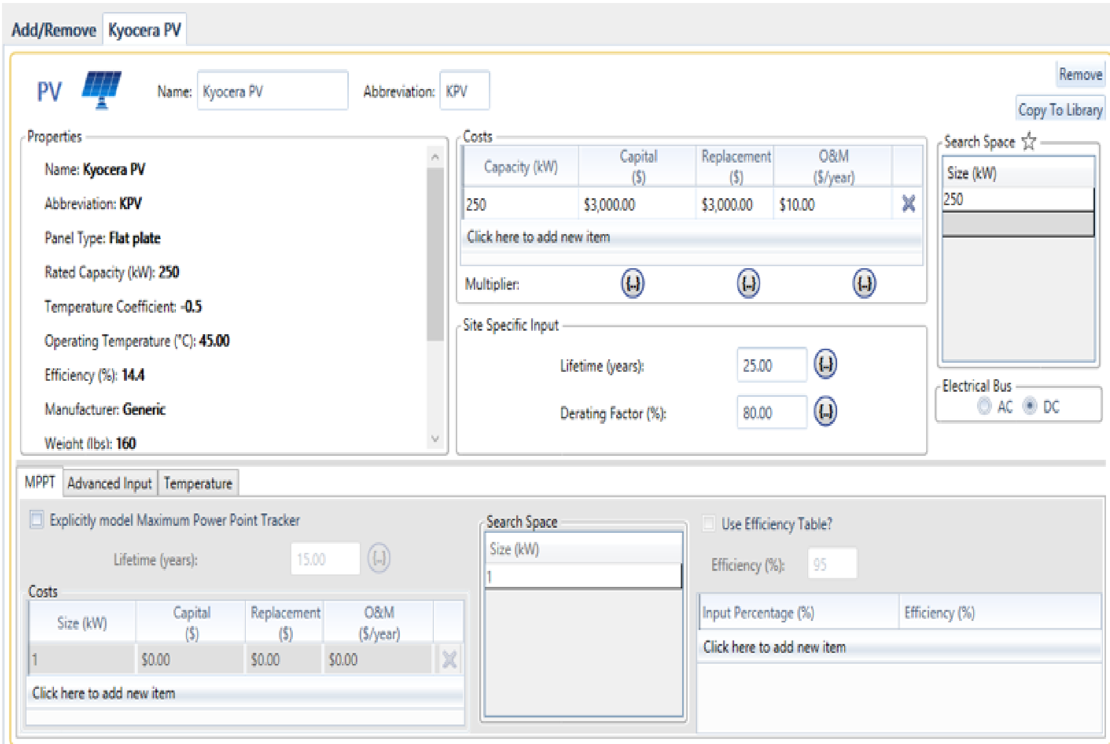

Figure 16. PV input model

4.3.4 Grid Input Characteristics

Grid power price was set to 0.12 US$/kWh according to the current power purchase agreement in Timor-Leste. Grid sellback was set to “ZERO” kWh because no FIT policy exists.

4.3.5 Inverter Characteristic Input

The inverter capacity and inverter efficiency were set to 250 kW and 90%, respectively.

4.3.6 Solar Radiation Input

Solar radiation data used in this simulation was the monthly average solar radiation data from 2015 to 2016. HOMER Pro automatically calculates clearness index values when solar radiation data is entered. Solar radiation data of the average of the given two years period can be viewed in figure 17, while for 2015 and 2016 can be seen in Annex A5 to A6.

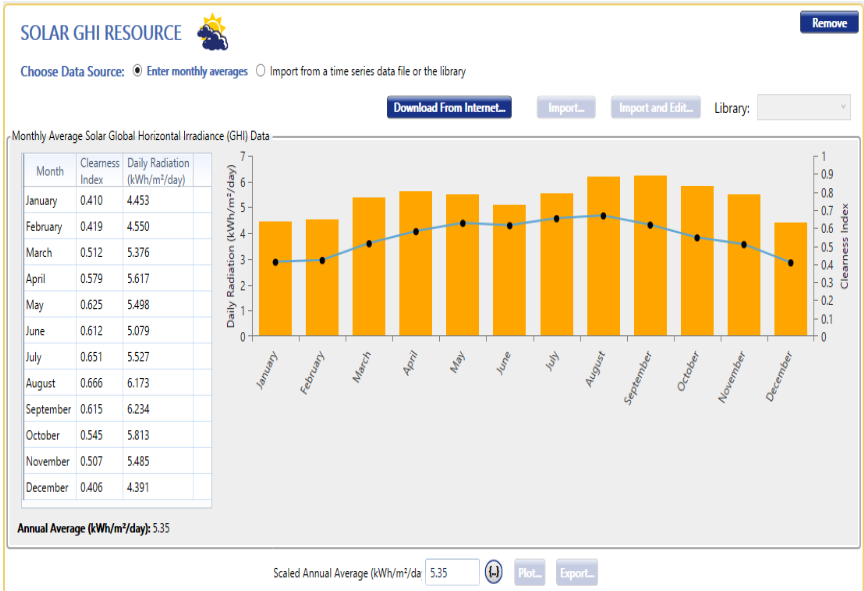

Figure 17. Average solar radiation values of the three years studied periods.

4.3.7 Temperature Input

Monthly average ambient temperature from 2015 to 2016 were used as an input. These temperature values were shown in table 5. In addition to that, an average temperature from 2015 to 2016 was also entered in the models as well. This average temperature can be viewed in figure 18.

Figure 18. Average temperature of the three years period.

4.3.8 Battery Input

The battery types used in the simulation tool were UET-ReFlex and CELLCUBE FB20-100. A sensitivity analysis will be performed by considering an increasing number of batteries, that is, different storage capacity of the system. The characteristics of the batteries included in the system are given in table 3 and table 4.

Table 3. The characteristics of the UET-ReFlex-100 kW battery.

Battery	Specification
Type	UET-ReFlex-100 kW
Lifetime	20 Years
Peak Power	120 kW_{AC}
Maximum energy	450 kWh_{AC}
Available State of Charge	100%
Efficiency $_{\text{peak Shaving}}$	$75\%_{AC}$
Efficiency $_{\text{frequency regulation}}$	$70\%_{AC}$
Voltage range	400_{AC}-10% to 480_{AC}+10%
Ambient temperature	-40^{0}C to 50^{0}C (-40^{0}F to 122^{0}F)

Table 4. The characteristics of the CELLCUBE FB20-100 battery.

Battery	Specification
Type	CELLCUBE FB20-100
Lifetime	20 Years
Nominal Capacity	100 kWh
Roundtrip efficiency	64%
Maximum discharge current	598.958 A
Output volatge	400 VAC

In this study, the minimum allowable state of charge, SOC, is 50%, the initial SOC is 100%, and assuming that charge and discharge occurs every day. Also, storage may be useful for buffering the electric grid when there is a sudden change of solar irradiation. The input variable of round-trip efficiency, is the round-trip DC-to-storage-to-DC energy efficiency of the battery bank or the fraction of energy put into the storage that can be retrieved. HOMER assumes that the storage charge efficiency and the storage discharge efficiency are both equal to the square root of the round-trip efficiency. Typical round-trip efficiency is about 80%. However, as both batteries have their own round-trip efficiency then those numbers were used to run in the simulation.

4.3.9 Control Unit

Control unit monitors the power monitoring unit of the system and delivers power based on the scenario: "The PV delivers the required energy to the building and store the excess energy in the battery. Battery supplies the required energy when there is insufficient solar radiation until it gets its Depth-of-Discharge, DoD".

4.4 Sensitivity Analysis

Sensitivity analysis was performed based on considering the uncertain parameters and removing the unrealistic combinations. Sensitivity analysis is the study of the sensitivity of a system when the parameters change their values (Salmani et al., 2014). HOMER Pro shows how the effect of the system changes with the fluctuation in load demand, solar radiation and ambient temperature. In this study, different sensitivity variables were considered to evaluate how the current PV system can meet the fluctuation of energy demand. In addition to that, a sensitivity analysis of PV system with battery and load fluctuation was also conducted. The fluctuation load demand considered in this sensitivity analysis were load demand increases by 50%, 100%, 150%, and 200%.

5. Results and Discussion

5.1 Solar Radiation and Ambient Temperature of the Site

Timor-Leste is located in the tropical region which have high humidity and temperature with a significant amount of rainfall, and cloudy sky affects the solar radiation incident on the PV system. In situation of cloudy weather, direct sunlight is scattered by cloud particles in atmosphere and hits PV module as diffused light thus affects the PV efficiency.

The average monthly value of solar radiation and the ambient temperature for 2015 and 2016 for the FEST of UNTL is depicted in table 5. The data was collected from the monitoring rooms of FEST of UNTL. The data recorded include the maximum, minimum, total and average values of all parameters over one-hour periods. Highest average solar radiation was about 6 kWh/m^2 and occurred in the months of August and September. On the other hand, the ambient temperature, was found to be higher during the month of November and it was lower during the month of July and August. Overall, annual average solar radiation and ambient temperature were about 5.35 kWh/m^2 and 26.57 ^{0}C, respectively.

Table 5. Average monthly solar radiation and ambient temperature for FEST of UNTL.

Month	Year					
	2015		2016		Average	
	Solar Radiation (kWh/m^2)	Aambient Temperature (degree C)	Solar Radiation (kWh/m^2)	Aambient Temperature (degree C)	Solar Radiation (kWh/m^2)	Aambient Temperature (degree C)
Jan	3.91	26.27	4.99	28.38	4.45	27.33
Feb	4.47	25.73	4.63	27.06	4.55	26.39
Mar	5.20	26.20	5.56	27.83	5.38	27.02
Apr	5.33	25.77	5.90	26.87	5.62	26.32
May	5.50	25.14	5.50	27.10	5.50	26.12
Jun	5.16	25.35	5.00	26.18	5.08	25.76
Jul	5.72	25.19	5.33	25.73	5.53	25.46
Aug	6.31	24.48	6.04	25.87	6.17	25.18
Sep	6.45	24.87	6.02	26.94	6.23	25.91
Oct	5.85	25.76	5.77	27.54	5.81	26.65
Nov	5.42	28.93	5.55	28.37	5.48	28.65
Dec	4.42	28.43	4.36	27.59	4.39	28.01
Average	**5.31**	**26.01**	**5.39**	**27.12**	**5.35**	**26.57**

5.2 Electrical Load Profile for FEST of UNTL

The FEST opens from 8.30 AM to 17.30 PM from Monday to Friday. Normally, educational activity starts from 9.00 AM and ends by 17.00 PM. At this time range, all equipment in all departments are to be ON for an average period of 9 hours. The total monthly electrical loads for the FEST during 2015 to 2016 and the average of the both periods are given in figure 19.

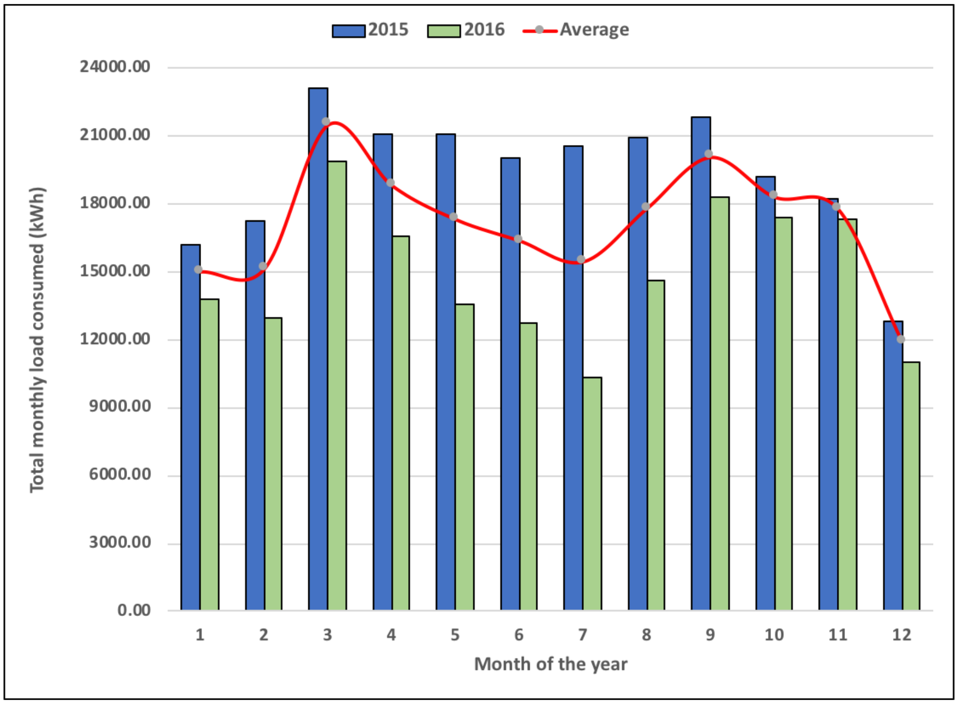

Figure 19. Total monthly energy consumption for the FEST of UNTL.

It can be seen from figure 19 that more electricity was used in 2015 compared to that of 2016. In 2015, the higher energy consumption occurred in the month of March while the lowest happened in December, accounting for about 23.13 and 12.83 MWh, respectively. This is because, in March, more laboratory activities were conducted, while December was the end of the academic year in Timor-Leste, so there were no more student's laboratory activities. Total energy consumed in 2015 was about 232.42 MWh. Similarly, monthly load values for 2016 was higher in March as well, accounted for about 19.90 MWh, and was less for July, accounted for 10.35 MWh with a total load of 178.60 MWh. The total annual average of energy consumption for both years was about 205.51 MWh. It can be observed that energy consumption in 2016 was reduced by 13% compared to the previous year. This phenomenon happened as FEST reduced its laboratory activities due to a financial issue (Faculty of Engineering, Science and Technology, 2018).

5.3 Diurnal Average Energy Generated and Energy Consumption

The average diurnal energy consumption of the FEST and energy generation of the PV system from 2015 to 2016 are presented in figure 20. The graph shows hourly monthly average energy demand and energy produce from the PV system. This trend represents the daily energy production and consumption from the system during the 24 hour per day per year.

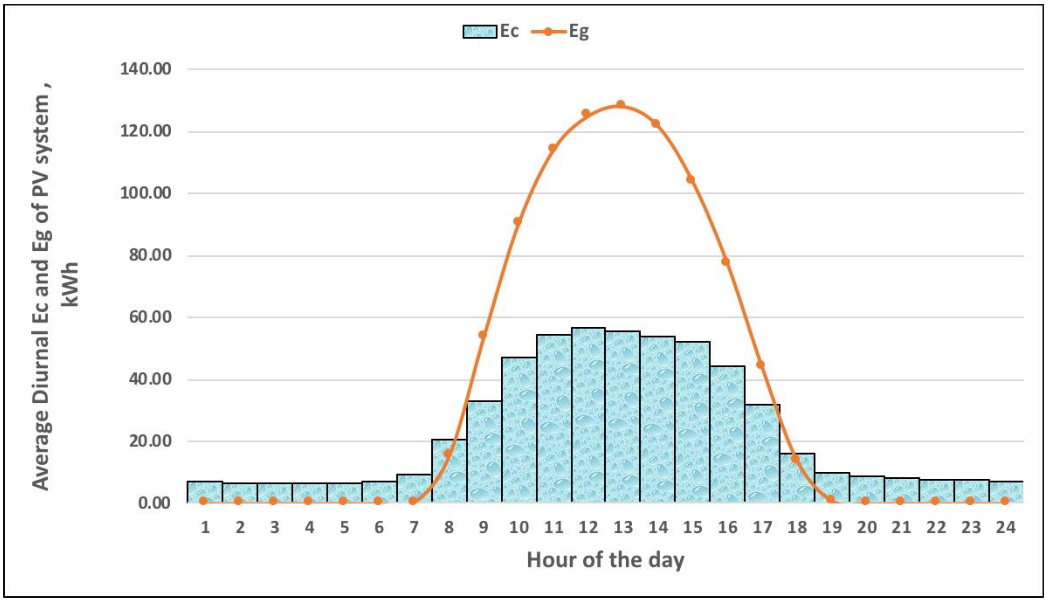

Figure 20. Diurnal average energy consumption of the FEST and energy generated by the PV system.

From figure 20, the average daily maximum energy consumption for the two years period was just about 56 kWh which occurred during the mid-day time. The minimum load consumption happened after learning activities finished and remained almost constant throughout the night until early in the morning; it accounted for around 7 kWh on average. The average monthly energy consumption was 565 kWh. On the other hand, monthly average energy produced by the PV modules was about 892 kWh.

Beyond the average values of energy generated by the PV modules and energy consumed by the FEST, the diurnal average energy generated by the system and FEST energy demand for each individual year were also presented. The average of daily energy uses trends for 2015 and

2016 were similar to the one presented in figure 20. The result can be seen in annex G2 and G3. The monthly average energy produced and load consumed in 2015 were about 960.67 and 639.71 kWh, respectively. The amount of energy consumed during the night until early in morning was about 9 kWh on average. As for 2016, the monthly average energy produced and load consumed were about 850.13 kWh and 488.31 kWh, respectively. The amount of energy consumed during the night until early in morning was about 5 kWh on average.

It can be observed that the majority of energy use in the engineering buildings is due to the laboratory activities. FEST laboratory activities start at around 10.00 AM to about 16.00 PM local time (Office of Faculty of Engineering, Science, and Technology. 2018). Regarding this time schedule of the engineering activities, the option for a PV system is favorable. This is because during this period energy from the sun is abundant. The study results show that the energy generated during that interval, from around 9 AM to 16 PM, is higher than that of energy consumed.

The study results also reveal that energy generated from the system was higher than energy consumed for both periods. This proves that energy generated was more than sufficient to cover the load demand and hence does not require to expand the system. Nevertheless, there is a potential to integrate battery storage with the system in order to store the excess of energy generated. Storing this excess energy in storage batteries permits it to be used to supply electrical load during night time or when the power from the grid is interrupted. Economically, install battery would require high capital cost but there are several technical benefits, such as communication benefit. For instance: student can still access to the internet when power from the main grid is interrupted. Another technical benefit is that the learning process continues to function whenever there is an interruption from the grid. Moreover, the FEST of UNTL can be categorized as self-sufficient energy consumption because during the day time, power is provided by the PV system while battery offers power at night time. This kind of benefits must be taken into consideration when decision is made. In addition, it is one of the measures that can be used to secure the continuity of power supply to the FEST buildings and to improve the reliability of the Hera PV system.

5.4 Energy Generated and Energy Injected to the Grid by the PV System

Figure 21 shows the total amount of energy generated by the PV plant. It can be spotted that PV modules produced more energy in 2015 compared to that of 2016. In 2015, the monthly energy produced ranged between a minimum of 23.32 MWh, in December, and a maximum of 35.36 MWh in September. For 2016, the energy generated values ranged from 16.21 MWh, in February, to 34.76 MWh in October. The annual average of total energy generated by the PV modules during the two years was around 324.94 MWh.

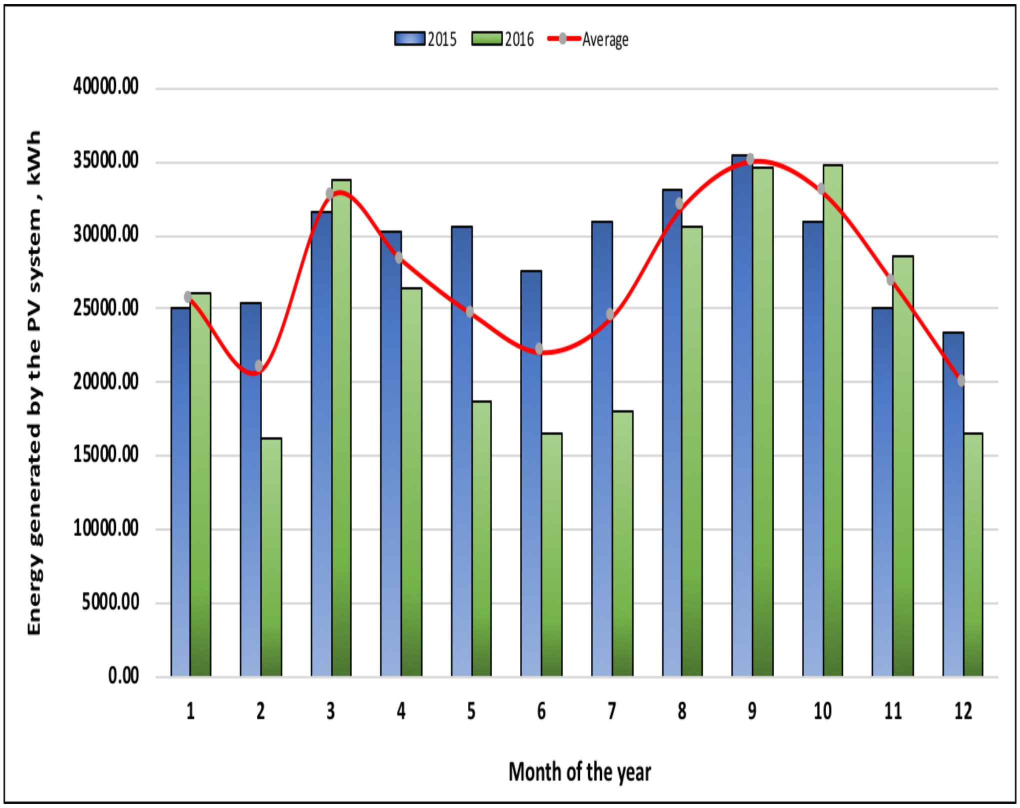

Figure 21. Energy generated by the PV system.

It can also be observed from the graph that energy generated in February, May to July, and December in 2016 was lower than values obtained in 2015. One aspect that contributed to the lower energy generated values is lower output from the PV modules due to higher cell temperature beyond 25 ^{o}C. This higher cell temperature is caused by the higher ambient temperature, *Ta*. This higher cell temperature will reduce PV modules voltage operating circuit (*Voc*) thus reduce the energy output from the PV modules. Amelia et al. (2016) conducted an investigation on the effect of temperature on PV panel output performance and found that, an increase of temperature of 10^0C would decrease the energy output of about 5%.

In terms of the energy exports, as it can be seen from figure 22, the monthly average of energy exported to the grid were ranged from 6.7 MWh to 19.1 MWh. Total annual average energy exported to the grid from 2015 to 2016 was about 162.6 MWh.

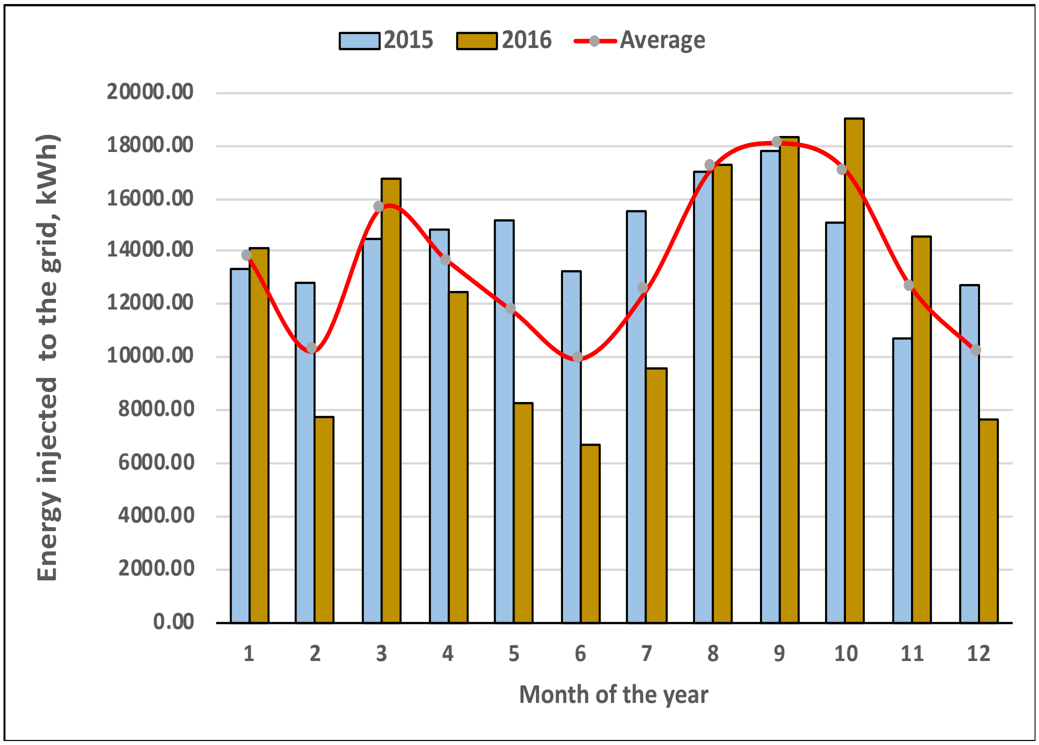

Figure 22. Energy injected to the grid from the PV system.

As far as I understood, there is no feed-in-tariff and there is no tariff at all. Energy could be paid at market price. The absence of this regulation has a negative impact for the FEST as a PV grid utility owner. It causes FEST-UNTL cannot earn economic benefits when the system supplies the excess of energy produced to the grid. This shows that the sustainability of the operating of the system cannot be guaranteed. In fact, the FEST has now found financial difficulties to do maintenance and to replace the broken inverters and PV modules. The absence of the FIT regulation can also affect the interest of other renewable electricity company to invest in the country. Accordingly, the renewable energy mechanism should be implemented to crab attention of investors. Despite renewable energy mechanism, policy such as capital subsidy, tax incentives, private investment, and foreign direct investment can also be employed to enlarge renewable energy sources. As without these mechanisms, it is very difficult to achieve the national goals and visions of renewable energy deployment. Nesamalar et al. (2017) stressed that policies and supports are essential for promoting renewable energy source-based generations.

5.5 Energy Supplied and Imported from the Grid to the FEST

Table 5 shows the monthly values of energy supplied by the PV plant and imported from the grid to the FEST for the period of 2015 and 2016. It can be observed that total energy supplied by the system and energy imported from the grid to the FEST was higher in 2015 and was less for 2016. The annual average of total energy shared by the system and brought from the grid were about 161.46 MWh and 43.18 MWh, respectively.

Table 6. Average energy supply to the FEST buildings.

Energy supply by the PV system and energy import from the grid to FEST buildings						
Month	Energy supply by the PV system			Energy import from the grid		
	2015	2016	Average	2015	2016	Average
Jan	11724.30	11912.10	11818.20	4461.56	1895.35	3178.46
Feb	12586.20	8491.07	10538.64	4689.24	4493.99	4591.62
Mar	17095.40	16985.00	17040.20	6030.11	2914.34	4472.23
Apr	15457.10	13861.80	14659.45	5648.27	2679.84	4164.06
May	15320.50	10501.98	12911.24	5764.51	3045.10	4404.81
Jun	14309.70	9798.89	12054.30	5701.82	2935.38	4318.60
Jul	15400.30	8364.53	11882.42	5129.32	1983.71	3556.52
Aug	16123.40	13280.40	14701.90	4841.14	1346.21	3093.68
Sep	17576.00	16290.50	16933.25	4287.91	1989.08	3138.50
Oct	15954.90	15727.10	15841.00	3260.55	1692.21	2476.38
Nov	12636.10	14039.30	13337.70	3874.25	3315.65	3594.95
Dec	10581.30	8900.99	9741.15	2238.59	2139.19	2188.89
Total	**174765.20**	**148153.66**	**161459.43**	**55927.27**	**30430.05**	**43178.66**

The overall amount of energy consumption, energy produced by the PV modules, energy exported and imported from the grid can be seen in table 6.

Table 7. Total energy production and consumption by the FEST

Year/Energies	Ep, MWh	Ee, MWh	Percentages, %	Ec, MWh	Ei, MWh	Percentages, %
2015	349.20	172.73	49.46%	232.42	55.93	24.06%
2016	300.68	152.53	50.73%	178.59	30.43	17.04%
Average	324.94	162.63	50.05%	205.51	43.18	21.01%

Where:

Ep = Energy produces by the PV modules (kWh)
Ee = Energy exports to the grid (kWh)
Ec = Energy consumptions of FEST (kWh)
Ei = Energy imports from the grid (kWh)

It can be seen that the system exported about half of its total energy generated to the grid, meanwhile the FEST imports less than 25% of energy from the grid to satisfy its energy demands. These values mean that the system injected a 50% of its total energy generated into the grid for free, while must pay for the 25% of energy that are imported from the grid. In order to minimize energy imports from the grid, attaching a battery to the system is a favorable option. By doing this, FEST will have sufficient energy supply from PV system and there is still excess energy supply to the grid for free.

5.6 System Reference Yield, Final Yield and Performance Ratio

To analyze the performance of the Hera PV Grid-connected system, data monitoring from 2015 to 2016 was used. The estimation was carried out by calculate relevant parameters for the average values. The calculation for the two years performed individually in order to compare the PV performance levels. The calculated parameters were the Y_F, the Y_R, and the PR. Operating results regarding to two years are presented in the next sections. The average Y_R, Y_F, and PR from 2015 to 2016 can be viewed in figure 23.

Figure 23 shows the annual average Y_R, Y_F, and PR trends from 2015 to 2016. It can be observed that Y_R ranged between a minimum of 4.39 kWh/(kWp.d), in December, and a maximum of 6.23 kWh/(kWp.d), in September. The annual average values of Y_F ranged from 2.49 to 4.52 kWh/(kWp.d). It also shows that the PR ranged from 57%, in December, to 73% in September. These values were very stable which indicated that the PV system has operated correctly.

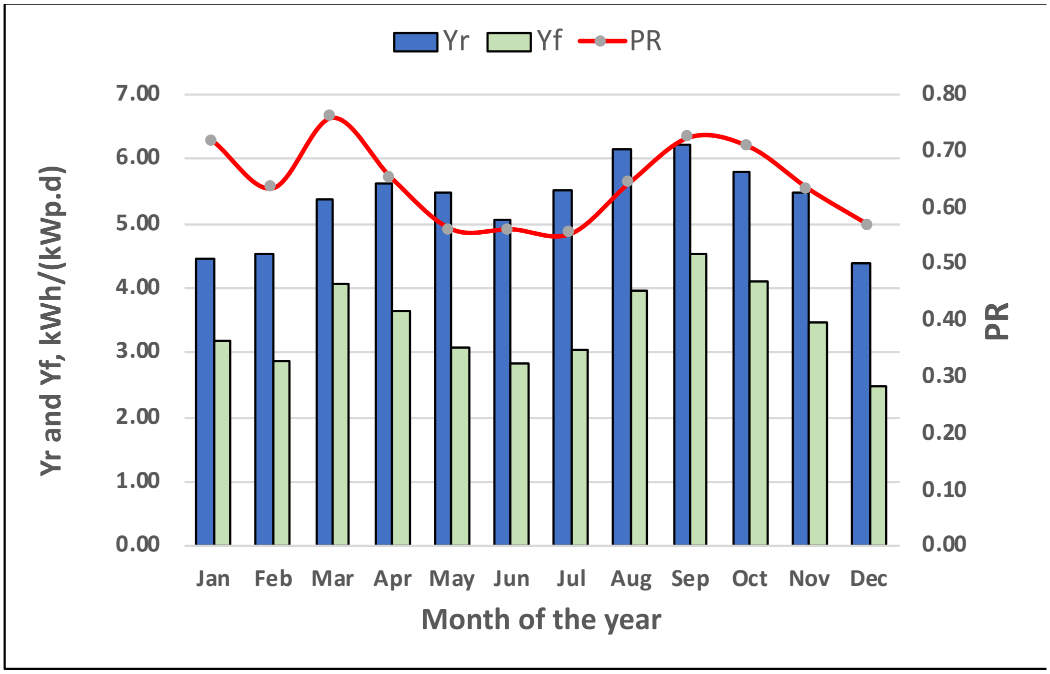

Figure 23. The annual average values of Yr, Yf, and PR.

However, the calculation of each individual year of operation were also carried on in order to see the trends of the system performance under real conditions. The study results show that, see annex E6, the monthly average values of *PR* for 2015 was less in November, accounting for about 59.63%, and was higher in January, accounting for around 80.13% with an annual average of 70.23%. The annual average value of Y_R and Y_F were around 5.31 and 3.71 kWh/(kWp.d), respectively. On the other hand, the annual average *PR* for 2016 was about 58.47%. While the monthly average values ranged between a maximum of 75.83%, in March, and a minimum of 42.13%, in July. The annual average value of Y_R and Y_F was 5.39 and 3.19 kWh/(kWp.d), respectively.

The study results reveal that the *PR* values of the system at the first phase of operation were higher. This is because the energy output, which represent by Y_F, increases with a good amount of solar radiation and a constant ambient temperature level. On the other hand, as for 2016, the *PR* was less due to higher ambient temperature. This higher ambient temperature reduced energy output, Y_F, of the PV modules slightly even there was a slightly increased of solar radiation. The trend can be clearly observed from table of summary of performance parameters values in annex E6.

The Y_F of other monitored system include: Morocco ranged from 1.96 to 6.42 kWh/(kWp.d) (Attari et al., 2016), India from 3.56 to 5.09 kWh/(kWp.d) (Kumar et al., 2015), and Greek from 1.96 to 5.07 kWh/(kWp.d) (Al-Otaibi et al., 2015). The average *PR* of other observed PV plant varied from country to country with an average value ranging from 49% up to 98%. A similar study conducted in Ghana found the PR ranges between 49% and 71% (Quansah et al., 2017); India, 80% (Kumar et al., 2017); in Serbia found the system *PR* was about 94% (Milosavljevic et al., 2015). In the similar study conducted in Morocco found the *PR* values was ranged from 58% to 98% (Attari et al., 2016), this trend shows the highest PR value among other observed countries. When comparing these *PR* values with the *PR* value obtained from Hera PV plants at the first-year of its' operations, the *PR* obtained was higher than that of in Ghana but lower than in Morocco, Serbia and India. In contrast, the *PR* values obtained in 2016 were lower than those in mentioned countries.

5.7 PV System Total Losses

The average monthly L_T values from 2015 to 2016 represented in figure 26 were calculated theoretically using the formula (4.4). The study results show that the average monthly Ls was different for each month. The monthly average L_T value was high for July, accounted for about 2.62 kWh/(kWp.d), and was less for January accounted for 1.37 kWh/(kWp.d) with an annual average of 2.04 kWh/(kWp.d). For each individual year, the average monthly L_T values of 2015 and 2016 were 1.74 and 2.34 kWh/(kWp.d), respectively. The changing values of both years can be seen in table of summary of performance parameters values in annex E6.

There are several factors that contributed to the L_T. One factor that caused higher Ls is cell temperature higher than 25 ^oC. This higher cell temperature is caused by higher ambient temperature, *Ta*. This higher cell temperature will lower voltage open circuit (*Voc*) of the PV modules. This low *Voc* reduces the Y_F, of the PV modules. Once the energy yield by the array plane, Y_A, is higher than Y_F, then L_T would be higher. Other factors that contributed to L_T are losses through cables due to the effect of the temperature on all the cables system. These losses are mainly due to long wiring between the PV system and the technical room. In addition to that, losses through energy conversion in the inverter also contributed to the system losses.

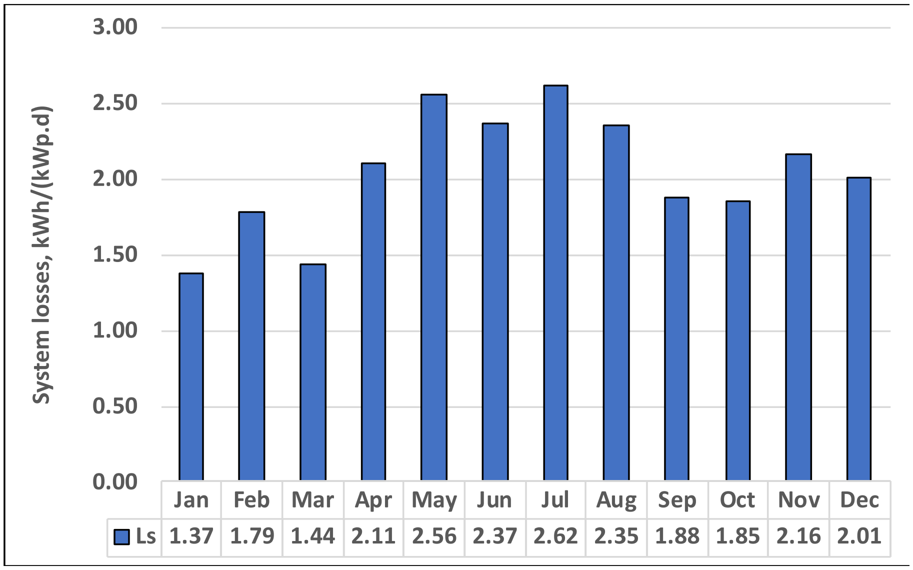

Figure 24. Monthly average PV system losses.

5.8 PV System Capacity Factor

The average monthly capacity factor (*CF*) values from 2015 to 2016 represented in figure 27 were calculated theoretically using the formula (4.5). The study results show that *CF* of the system was varies from month to month. The monthly average *CF* value was high for September, accounting for about 19.44%, and was less for December, accounting for 10.72% with an annual average of 14.83%.

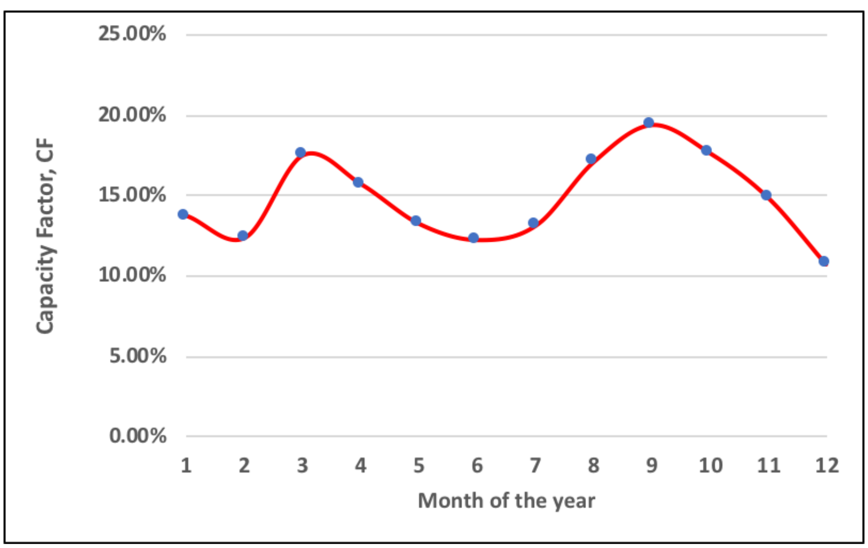

Figure 25. Capacity factor of the installed PV system.

The calculation of *CF* for each individual year was also performed, see annex E4, in order to compare the average values of *CF* occurred under the real operating conditions. The study results show that the annual average *CF* values for 2015 was higher than that of in 2016, accounted for around 15.94 and 13.71%, respectively. While the monthly average *CF* values, in 2015, ranged from 12.54% to 19.65%, and as for 2016 was between 8.91% and 19.23%.

The study results indicate that monthly *CF* values varied from month to month. These values variation was due to the system losses as a result of local climate conditions. The *CF* values of others similar studies shows that, according to Kumar and Sudhakar (2015), a *CF* value varied from 12.67% to 20.04% based on one-year operation. Overall *CF* for the Indian PV plants varied from 12.29 to 18.8%. Attari et al. (2016) conducted a performance investigation on a PV grid-connected system in Morocco and found the annual *CF* of the system to be 14.84%. There were also studies conducted by Makrides et al. (2007) on performance assessment of a fixed PV system, found the *CF* annual average value to be 19.4%. Other studies conducted by Gottschalg et al. (2005) found *CF* values between 20.8% and 26% for south-facing fixed and dual-axis tracking PV systems in Cyprus, respectively. To the knowledge of the author, there were no previous documentation or studies of *CF* for a fixed PV system in Timor-Leste. However, it can be deducted that *CF* value higher than 8.91% and less than 19.65% is a reasonable for a fixed PV system. The annual average *CF* value obtained in this study was 14.83%.

5.9 PV Modules Efficiency

Figure 26 shows the average performance of polycrystalline module under real conditions of operation from 2015 to 2016. It can be observed that the average monthly PV module efficiency values varied for each month. The monthly average PV module efficiency value was high for March, accounting for about 11%, and was less for July, accounting for 8% with an annual average of 9.33%. For each individual year as it can be seen in table of summary of performance parameters values in annex E6, the average monthly PV module efficiency values of 2015 and 2016 were 10.17 and 8.47%, respectively.

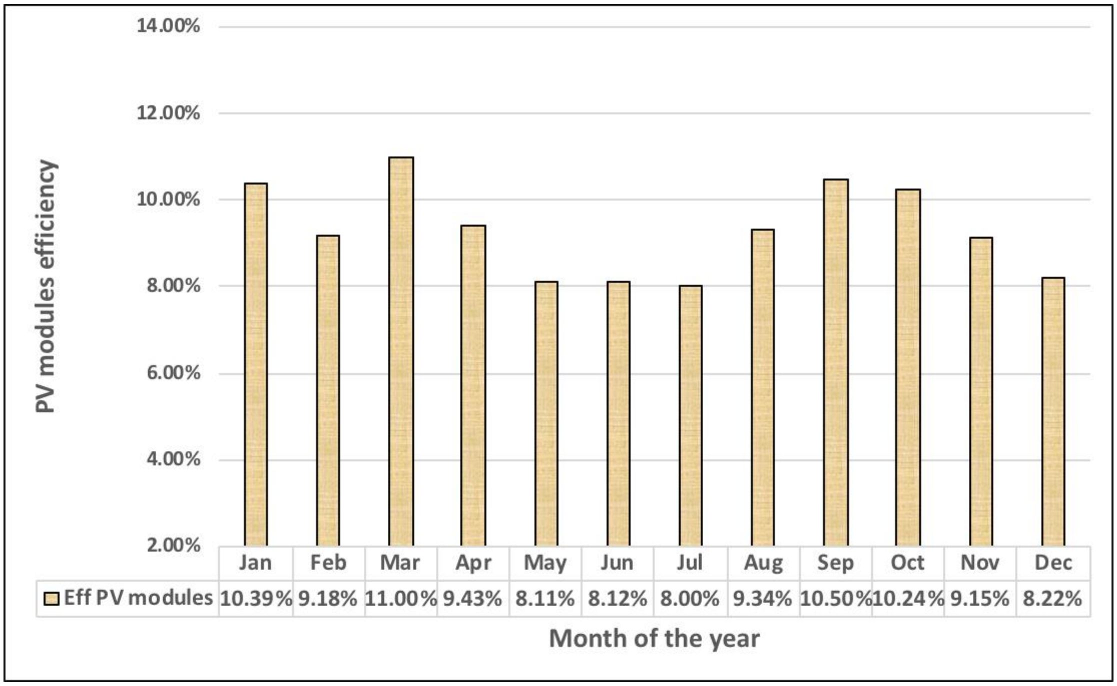

Figure 26. Monthly average PV module efficiency.

These trends of the PV array efficiency are due to lower PV array output. One aspect that could lower the PV array efficiency was high ambient temperature. As the ambient temperature higher, the cell temperature will increase which causes the voltage open circuits of the PV modules drops. Consequently, energy generated from the PV array will be low. Beyond that, efficiency is also affected by the energy conversion losses in the inverter and system losses. Therefore, the efficiency of the PV modules was lower compared to the levels provided by the manufacturer.

5.10 PV System Efficiency

Table 8 displays inverter and system efficiency under factual conditions of operation. It can be observed that the PV plant efficiency values were different from 2015 to 2016. The average monthly inverter and PV system efficiency was high for 2015, and was less for 2016. This is because the efficiency of the PV modules and the inverter efficiency decreased. This reduction was due to less energy output from the PV arrays which reduce the PV array efficiency.

Table 8. Annual average of Inverter and PV system efficiency.

Year	h_{INV}	h_{PV}
2015	70.61%	7.23%
2016	58.78%	5.21
Average	**64.80%**	**6.05%**

The average monthly values for each individual year can be seen in table of summary of performance parameters values in annex E6, as it can be noticed that the average monthly PV system efficiency values of 2015 ranged from 5.18 to 9.35 %. While the inverter efficiency ranged from 59.95 to 80.57%. As for 2016, the maximum inverter efficiency was 76.25% and minimum of 42.35%.

5.11 Simulation Results of PV System with Battery

The simulations of several scenarios incorporating storage batteries in the system are made through the HOMER Pro software and some results are exposed. These results will determine the conclusions that we will ascertain for this dissertation. In this section, simulation results are provided based on the average values from 2015 to 2016. Simulation based on yearly data were also conducted to compare and evaluate the effects of load fluctuation to the simulated battery capacity.

5.11.1 Simulation Result for the Average data from 2015 to 2016

The overall results of simulation of PV system plus batteries with a different characteristic are shown in table 9. The table shows, according to each case simulated, the type of battery as well as the capacity and the energy that has to be purchased from the grid. The overall simulation results with HOMER Pro software can be seen in annex F1 and F2.

Table 9. Summary results of simulation of PV system with batteries.

System, S	Batteries					System			PV	Grid	
	Type of batteries	N batteries	Capacity, kWh_AC	Autonomy, hr	Annual throughput, kWh	Ren Frac, %	Energy Production, kWh/year	Energy Consumption, kWh/year	Energy generation, kWh	Energy Purcharged, kWh	Energy Sold, kWh
S1	UET ReFlex -100kW	4	450	51	59051	100	365776.6	313746.1	365249	527	107554
		2		25	53889	99	369762.9	318937.1	365249	4514	112745
		1		13	47576	97	374636.5	325247.1	365249	9387	119055
S2	CELLCUBE FB20-100	6	100	25	56861	98	370431	311552.5	365249	5182	105360
		5		21	55158	98	371657.3	313356.2	365249	6408	107164
		4		17	52982	97	373224.3	315692.1	365249	7975	109500
		3		13	49924	97	375425.8	319019.3	365249	10176	112827
		2		8.5	45913	96	378313.9	323419.6	365249	13065	117227
		1		4.2	32248	93	388152.4	338679.8	365249	22903	132488

Table 9 shows the overall results of PV System connected to batteries with the load demand, solar radiation and temperature data based on the average values from 2015 to 2016. Battery of two different types and capacities were chosen to run this simulation. The UET ReFlex-100 kW type was considered to be system S1, and CELLCUBE FB 20-100 was considered to be system S2.

The simulation results show that the optimum choice selected by the HOMER Pro for system S1 was 4 batteries per string. This is because annual battery energy throughput and battery autonomy are higher compared to the system with 2 batteries and a single one. Beyond that, energy purchase by S1 with 4 batteries is lower than that of system with a single and 2 batteries. However, energy production by system S1 in all cases is higher than energy consumption. Also, autonomy of 1 battery and 2 batteries is sufficient to serve FEST load during grid interruption and even can serve loads at night. So, the optimum choice of battery could be a system with a single battery.

As for S2, HOMER Pro selects S2 with 6 batteries per string as the best option. This is because the autonomy of 6 batteries per string is higher than those below 6. The system energy production of all batteries is higher than the FEST energy consumption. However, as the battery capacity is quite low, it is useful to look at the battery with a reasonable number of days of autonomy to decide a battery size. From the result obtained from the simulation, it is possible to decide that for system S2, the right choice could be system with 4 batteries per string.

5.11.2 Simulation Result for 2015 data with Battery

The simulation results for 2015 with batteries can be seen in table 10. As for system S1, the HOMER Pro selects 4 batteries per string as the most convenient option. However, considering battery autonomy and energy generated by the system, a single battery and 2 batteries need to be considered as well. In such case that battery with autonomy of one day is considered and the energy consumption is assumed to be constant, then option could be the system with 2 batteries per string. But, if the assumption is made upon the energy generated by the PV system due to abundant sunlight during the day, then a single battery could be a preferable option.

Considering system S2, the simulation results led to a 6 batteries per string as the best option. In such case that solar fraction and the autonomy criteria of the system of one day are considered, then option could be the one selected by HOMER Pro. Nevertheless, if it is considered that there is more solar production during the day and the energy stored in the battery would be used only during the night, then a system with 4 batteries per string could be more than sufficient.

5.11.3 The Simulation Results for 2016 data with Battery

The simulation results for 2016 with batteries are shown in table 10. Considering system S1, the simulation results show that HOMER Pro selects a system with 4 batteries per string as the preferable option. In such case that FEST would like to independent from the grid, then HOMER Pro selection can be accepted. This is because the system can cover FEST energy demand at about 100% which make the FEST become energy self-sufficient. However, in such case that FEST would like contributes some of system energy generated to the grid then a system with single and 2 batteries could be a preferable choice.

As for system S2, HOMER Pro selects a system with 6 batteries per string as the optimal option. In the case that autonomy of one day is considered then option can be as the same at HOMER Pro suggested. Nevertheless, in such case that energy production and energy consumption is considered then the optimal option could be a system with single and 2 batteries per string.

Table 10. Summary simulation of 2015 and 2016 data of PV system with batteries.

Year	System, S	Batteries					System			PV	Grid	
		Type of batteries	N batteries	Capacity, kWh_AC	Autonomy, hr	Annual throughput, kWh	Ren Frac, %	Energy Production, kWh/year	Energy Consumption, kWh/year	Energy generation, kWh	Energy Purcharged, kWh	Energy Sold, kWh
2015	S1	UET ReFlex-100kW	4	450	45	74646	99	366744.4	310016.1	364370	2374	76628
			2		22	68222	98	371704.5	316755.4	364370	7335	83367
			1		11	59002	92	378823.2	326357.3	364370	14453	92969
	S2	CELLCUBE FB20-100	6	100	23	71359	97	373000.9	308115.8	364370	8631	74728
			4		15	65583	96	377159.9	314612.0	364370	12790	81224
			2		7.5	54051	94	385462.1	327360.1	364370	21093	93972
2016	S1	UET ReFlex 100kW	4	450	58	40224	100	361533.8	314401.9	361218	315	135638
			2		29	38941	99	362524.5	315748.1	361218	1306	136984
			1		15	34928	99	365623.3	319958.3	361218	4405	141194
	S2	CELLCUBE FB 20-100	6	100	29	41331	99	362832.9	310146.8	361218	1614	131383
			4		20	38966	99	364536.3	312808.5	361218	3318	134045
			2		9.8	33606	98	368395.0	318837.7	361218	7177	140074

5.12 The Sensitivity Analysis Result

For the sensitivity analysis, the parameters consider, such as climate data and electrical load are based on 2015 data. The reason for chosen this particular period is due to its high load demand compared to 2016. Therefore, it is assumed that these data are more representative to run in this simulation tools. The fluctuation load demand considered in this sensitivity analysis are load demand increases by 50%, 100%, 150%, and 200%. This percentages are taken based on the real condition that Faculty´s load demand will increase because currently the FEST is under progressing of constructions. The FEST building progressing can be seen in the figure 27.

Figure 27. FEST building construction development.

Sensitivity Analysis of PV System only with Load Variation Results

The simulation results of the current system capacity with the current average annual energy demand are presented. Beyond that, the simulations of current system capacity with load fluctuation scenario are also executed. Attention is given to the energy generation from the current PV modules in response to any load increase from the current load's levels.

Scenario 1: Current PV Capacity and Energy Demand

Figure 28 shows the energy output from the system which represented by *x-axis*, and according to the time which represented by *primary y-axis* and *secondary y-axis* represented PV power output.

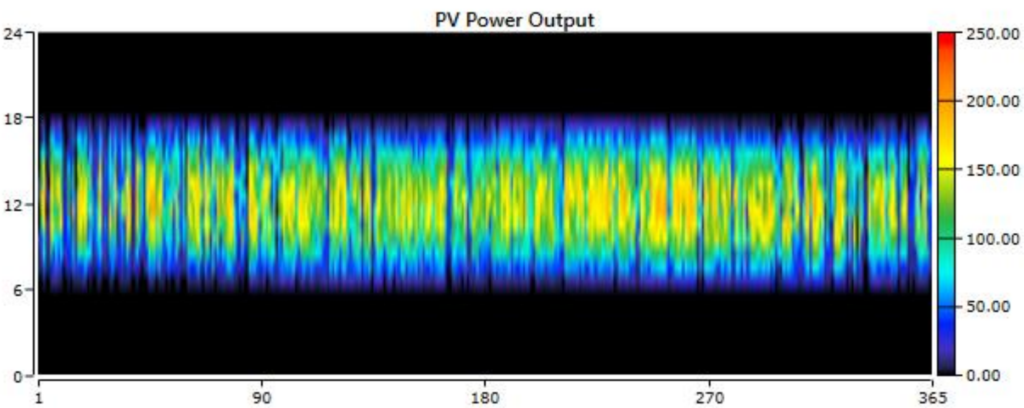

Figure 28. Energy output of the PV modules.

PV modules operate 4015 hours per year with a mean output of 40.93 kW and a maximum output of 207 kW. The system produces about 358.51 MWh/year with a solar penetration of 85.53%. This value signifies that almost 85.53% of the energy demand has the ability to be met by solar energy. As it can be observed the energy output is stronger in the middle of the day during the whole year. However, the PV modules produce less energy often in rainy season due to frequent rains.

Monthly Power Generation

Figure 29 represents the total power production for each month of the year, including power production by the PV system and grid purchases. In the case of peak power production, there is an excess of electricity which is not used to meet the load and is dumped to grid. On the contrary, in the event of high demand and less PV output, electricity is imported from the grid.

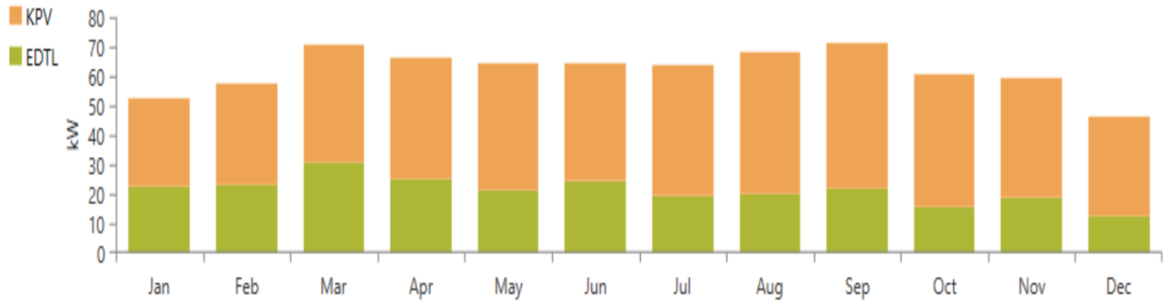

Figure 29. PV power production and power imports from the grid.

As it can be noticed the highest electricity import occurs in March while the lowest occurs in December.

Scenario 2: Current PV Capacity and Increasing Energy Demand

Figure 30 shows the overall sensitivity results of load demand fluctuation that are increased by 50%, 100%, 150%, and 200% from the current level.

Sensitivity	Architecture								System				PV	Grid	
Electric Load #1 Scaled Average (kWh/d)					PV (kW)	Grid (kW)	Converter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Excess Elec (kWh/yr)	Production (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
1278.84					250	999,999	250	CC	64	543766.1	507915.6	0.0007214409	358,510	185,257	41,139
1598.55					250	999,999	250	CC	54	637291.4	601439.9	0.001225383	358,510	278,782	17,970
1918.26					250	999,999	250	CC	46	743730.1	707877.3	0.002078144	358,510	385,221	7,714
639.41928					250	999,999	250	CC	84	419158.4	383307.6	0.0001198158	358,510	60,649	149,919
959.13					250	999,999	250	CC	74	470981.9	435129.9	0.0002509382	358,510	112,472	85,049

Figure 30. Sensitivity analysis results of PV system plus load fluctuation but without battery.

The sensitivity analysis results, as can be observed from figure 30, of the effect of growths in energy demand show that the constant increases of energy demand would have impacts on current system capacity. As it can be seen HOMER Pro selects the preferable option of an increase load by 1,278.84 kWh/d of a PV energy production value of 358,510.00 kWh/year which account for 64% of total energy generation. Since the PV production occurs during the day time, typically between 7 am to 6 pm, it is able to meet the energy demand during that time but not in evening. Therefore, resulting in grid sales of 41,139.00 kWh/year. This is because during mid-day when the energy production exceeds energy demand, a huge amount of energy is exported to the grid. Total of 185,257.00 kWh/year of energy is imported from the grid during evening or when the energy demand exceeds the PV production, this accounts for 36% of the total energy generation. So, resulting in a total energy production of 543,766.1 kWh/year.

Figure 30 also shows that the addition of load demand results in energy export reduction and energy import increase. However, as energy import increases higher than energy export when load demand increases, the renewable fraction decreases. Indeed, 84% of the energy generated by the current system capacity is consumed for lower load, accounted for 639.42 kWh, while decreased to about 64% when load demand reaches 1278.78 kWh. It means that the shape of the load demand appears to be a constraint to the current system capacity because the magnitude of energy demand depend on the current PV production inevitably results in increasing energy import. Therefore, HOMMER Pro simulation tools selects an increase load demand up to 100% from the current levels as the optimal choice.

Scenario 3: Current PV Capacity plus Battery with Increasing Energy Demand

The next scenario is by adding batteries to the system. UET ReFlex-100 kW batteries are used in this simulation. The battery search space is set to 2 batteries. The overall simulation results can be seen in annex E8. The results were obtained with a load-following strategy which means that the batteries are only charged with the excess of PV system output. It can be observed that the optimal number of batteries is 2, which will be one string with 2 batteries in parallel. The SOC of the battery is presented in figure 31.

Figure 31. The State of Charge of the UET ReFlex-100kW battery.

It can be noticed from figure 31 that the SOC of the batteries is almost 100% during the year, because there is an excess of energy that is stored in the batteries during the day. The batteries annual energy input is 45,121 kWh and the annual energy output is 33,515 kWh. The batteries can supply the load with an autonomy for 11.16 hours, and the expected battery life is 20 years, where the renewable fraction is 67%.

Sensitivity	Architecture			System			KPV	UniSystem			EDTL
FEST of UNTL Scaled Average (kWh/d)	KPV (kW)	UniSystem	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)
1278.84	250	2	LF	67	513602.4	467306.4	358,510	2	11	39,066	155,093
1598.55	250	2	LF	55	623790.3	583470.1	358,510	2	8.9	17,486	265,281
1918.26	250	2	LF	46	737776.9	700162.8	358,510	2	7.4	7,710	379,267
639.41928	250	2	LF	97	366614.3	311969	358,510	2	22	68,052	8,105
959.13	250	2	LF	84	415309.4	359862.1	358,510	2	15	72,104	56,800

Export... Optimization Cases: Left Double Click on a particular system to see its detailed Simulation Results. Categorized Overall

Architecture			System			KPV	UniSystem			EDTL	
KPV (kW)	UniSystem	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	2	LF	67	513602.4	467306.4	358,510	2	11	39,066	155,093	530
250	1	LF	67	515599	469832.1	358,510	1	5.6	36,481	157,089	3,055

Figure 32. The sensitivity analysis results of load fluctuation with PV system plus battery.

In the case that the load is at a constant level of about 639.42 kWh per day, then the PV system with 2 batteries would provide energy at about 97%, and the number of days of autonomy is increased to about 22 hours. It means that FEST can be self-sufficient with renewable energy supply. When energy demand increases to about 200%, then the batteries would only have 7.4 hours of autonomy. Any energy demand increase beyond that level would decrease battery autonomy and increase energy import. Accordingly, for a system with 2 batteries, the system is capable to supply energy up to 200% from the current energy demand levels. Having a large energy demand has effect on the available PV system capacity, because the scale of energy demand depends on the current system production. Although PV generation varies over days and hours but only generates energy during day-time and meets energy demand during that period. Therefore, it is important to control the fluctuation of energy demand that could meet the PV production.

6. Conclusions and Recommendations

6.1 Conclusions

The first PV system connected to the grid in the FEST in Timor-Leste was a government project. In this dissertation a performance analysis was carried out in order to observe the system behavior under the specific real climate conditions. In addition to that, simulations of the PV system with batteries were also performed in order to observe how the system can meet load demand. A sensitivity analysis of load fluctuations was also conducted in order to comprehend the available capacity with increasing load demand. The simulations of the PV system with batteries were modelled in the HOMER Pro simulation tool. The HOMER Pro was utilized as the assessment tool with hourly load data input from the FEST buildings. The input load data and climate data used were from 2015 to 2016, including the average data of both years.

From the nominal installed power, the average annual energy produced by the system, the annual energy consumed by the FEST buildings, the *Yf*, the *PR*, the *CF*, and the system efficiency were estimated. It was found that, the annual average energy consumption by FEST and energy generated by the PV system from 2015 to 2016 were about 205.51 and 324.94 MWh, respectively. While energy imported from and exported to the grid were about 43.18 and 162.63 MWh, respectively. The *PR* ranged from 55 to about 76% with an annual average of 64%, the annual average of *CF* was 14.83% and PV module efficiency was about 9.33%.

As for each individual year, the results of the study show that the total energy generated was higher for 2015, accounted for 349 MWh, and about 301MWh in 2016. The total FEST energy consumption was about 232 MWh in 2015 but it reduced to about 179 MWh in 2016. The annual average value of *PR* was higher for 2015, about 70%, and about 58% in 2016. The PV modules efficiency was quite lower for both years compared to the nominal efficiency of 14.4% from the PV manufacturer.

Simulation that include load fluctuations without battery were conducted. The simulations results indicate that the system could afford to supply energy up to 100% of the current load demand levels. Any changes beyond that levels would increase the energy imports from the grid. While the simulation results of the PV system plus two UET ReFlex-100kW batteries with load fluctuations indicate the system could afford to supply energy up to 200% from the current load demand levels. However, when load increases beyond that levels, the energy supply from the system becomes insufficient, the battery autonomy also reduces, and more energy imported from the grid would be necessary.

In conclusion, after the study carried out in the present work, it is concluded that the photovoltaic plant installed in the FEST buildings has an acceptable performance. The system satisfies FEST energy consumption during the day and also injected a vast amount of energy to the grid. An increase of load in the future would have an impact on the available PV capacity but it can be managed with a load management technique.

6.2 Recommendations

From the study results, the following recommendation is proposed in order to keep the system perform well during its operations:

- The study results show system output exceeds load demand, resulting in excess of energy which can be absorbed by adding batteries. Therefore, attaching batteries to the system should be developed in order to respond to further load increase.
- The inverter efficiency is poor, resulting in lower plant efficiency as expected. Accordingly, it is recommended to replace the inverter to improve the system reliability.
- The study results provide a clear information for the government in order to expand and implements the same project to other government institutional especially for those institution that has no access to the grid. In addition to that, it provides information to the top decision maker in the government institutional to select the appropriate types, grid connected or stand-alone systems, of the system based on energy demand requirements and local conditions. In the absence of the FIT policy, it is recommended to develop stand-alone system for further installation.
- Allowing other educational institution to access to the system to expand the benefits of this technology and as well as for academic researcher to conduct research.
- Promote the benefits of the system to the students and engaging them in the maintenance tasks. It would strength their sense of belongings to the system.
- Conducting a regular inspection and maintenance to avoid any damages to the system.

- As for the potential for the use of wind energy, the results obtained indicate that wind speed at 3 meters from ground is quite low. Therefore, it is recommended for further investigation of wind speed at higher distances from ground and also at other locations inside, or close by, the perimeter of the Faculty.

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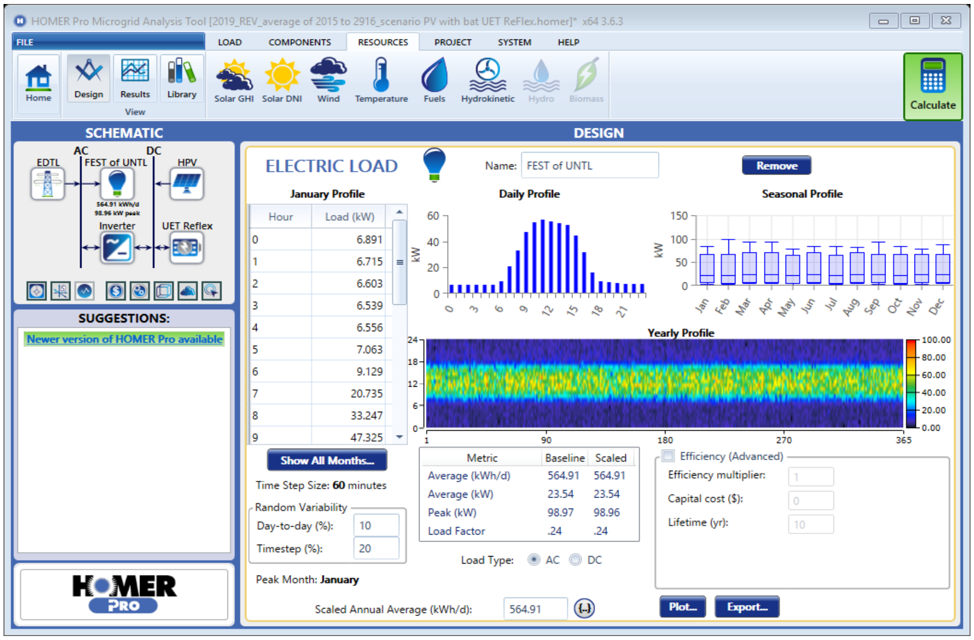
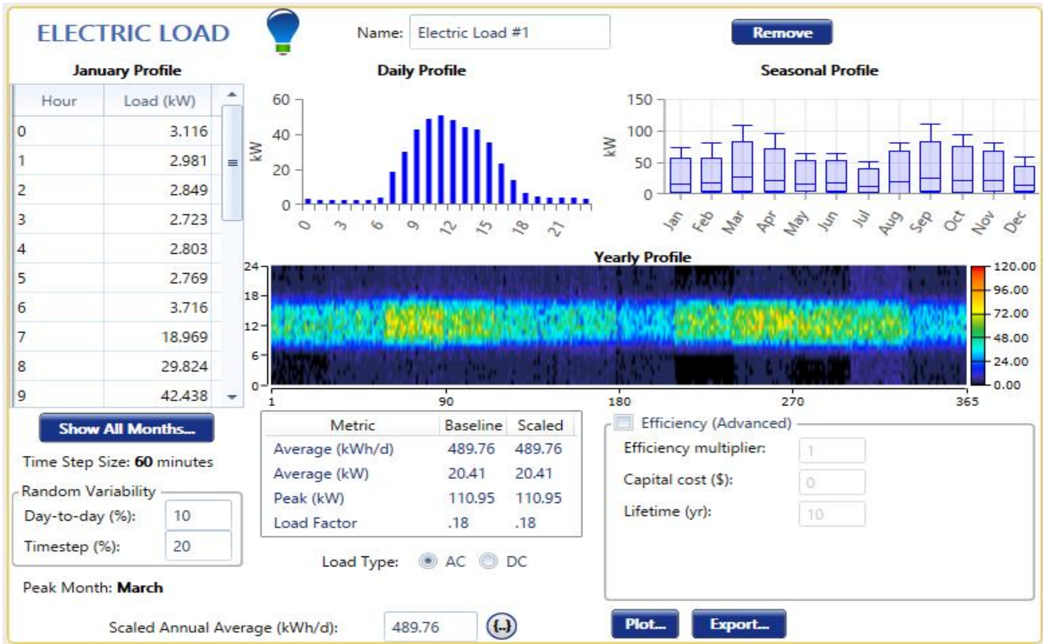
ANNEX A. INPUT PARAMETERS FOR HOMMER PRO SIMULATION TOOLS

1. Average electrical load input from 2015 to 2016

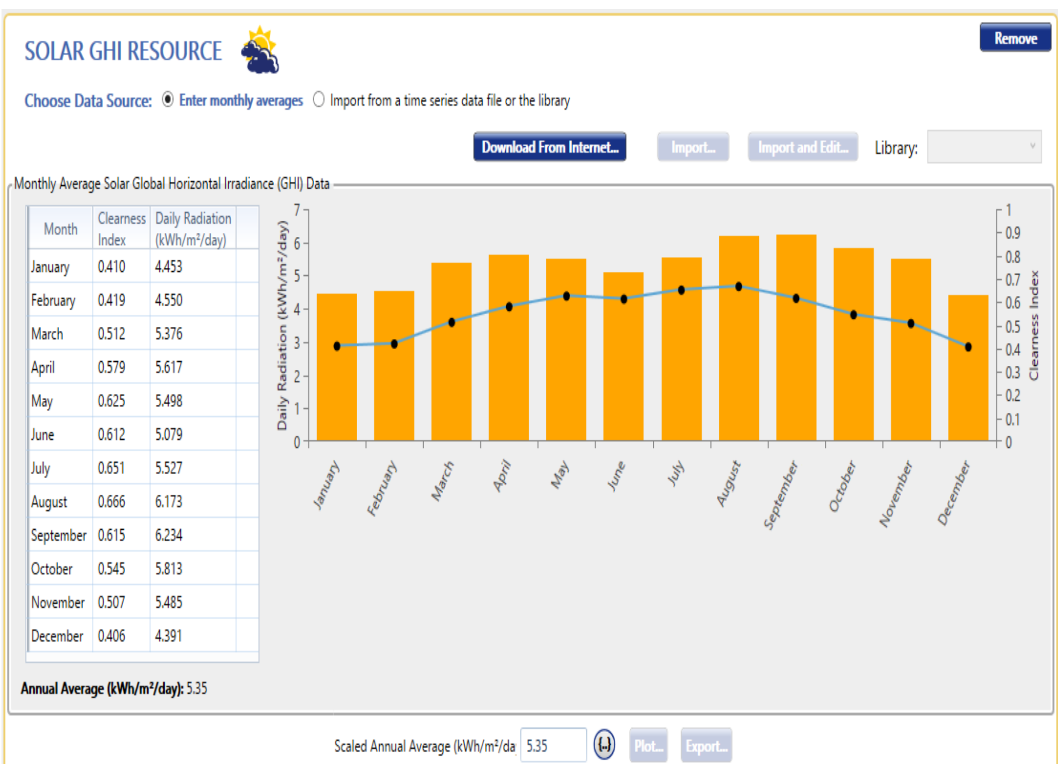


2. Electrical load input for 2015

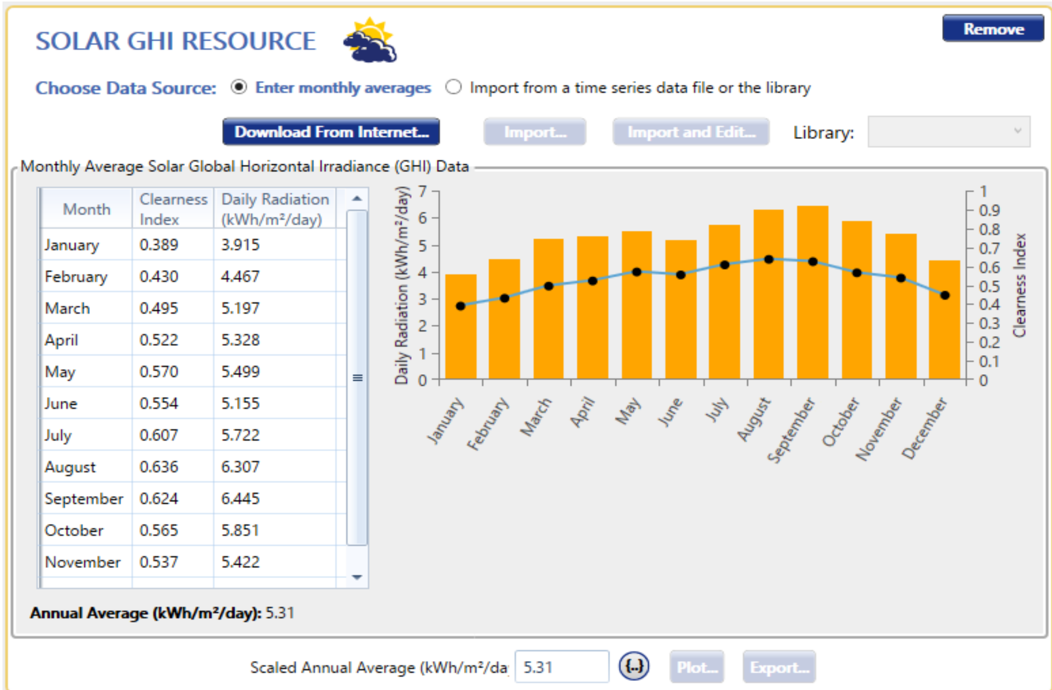
3. Electrical load input for 2016



4. Average solar radiation from 2015 to 2016

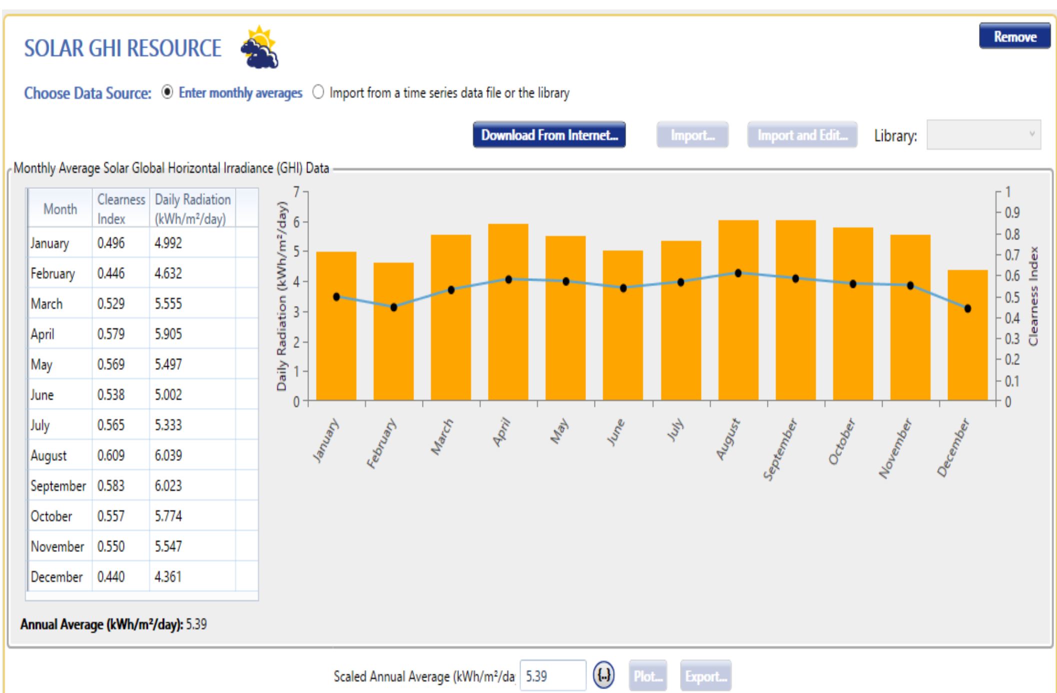


5. Solar Radiation Data for 2015



Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.389	3.915
February	0.430	4.467
March	0.495	5.197
April	0.522	5.328
May	0.570	5.499
June	0.554	5.155
July	0.607	5.722
August	0.636	6.307
September	0.624	6.445
October	0.565	5.851
November	0.537	5.422

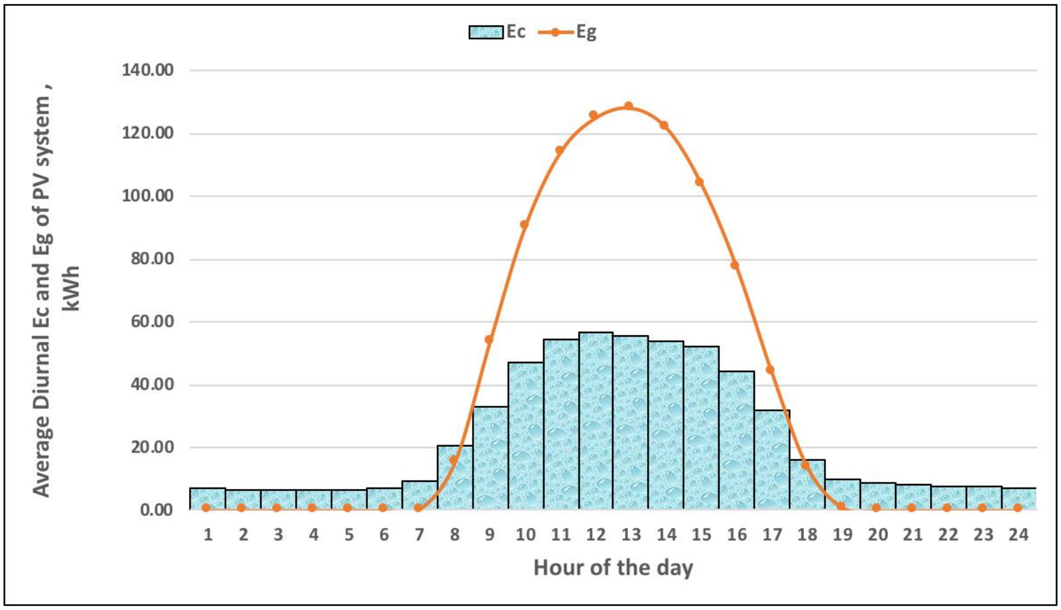
6. Solar Radiation Data for 2016



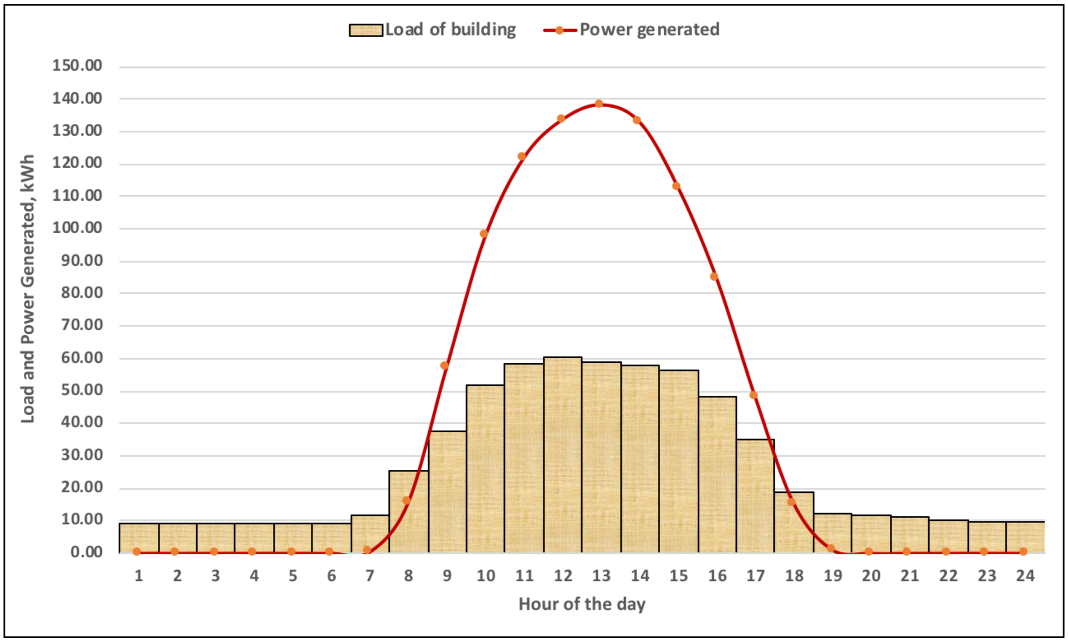
Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.496	4.992
February	0.446	4.632
March	0.529	5.555
April	0.579	5.905
May	0.569	5.497
June	0.538	5.002
July	0.565	5.333
August	0.609	6.039
September	0.583	6.023
October	0.557	5.774
November	0.550	5.547
December	0.440	4.361

ANNEX B – GRAPHS OF DIURNAL LOAD AND PV GENERATION

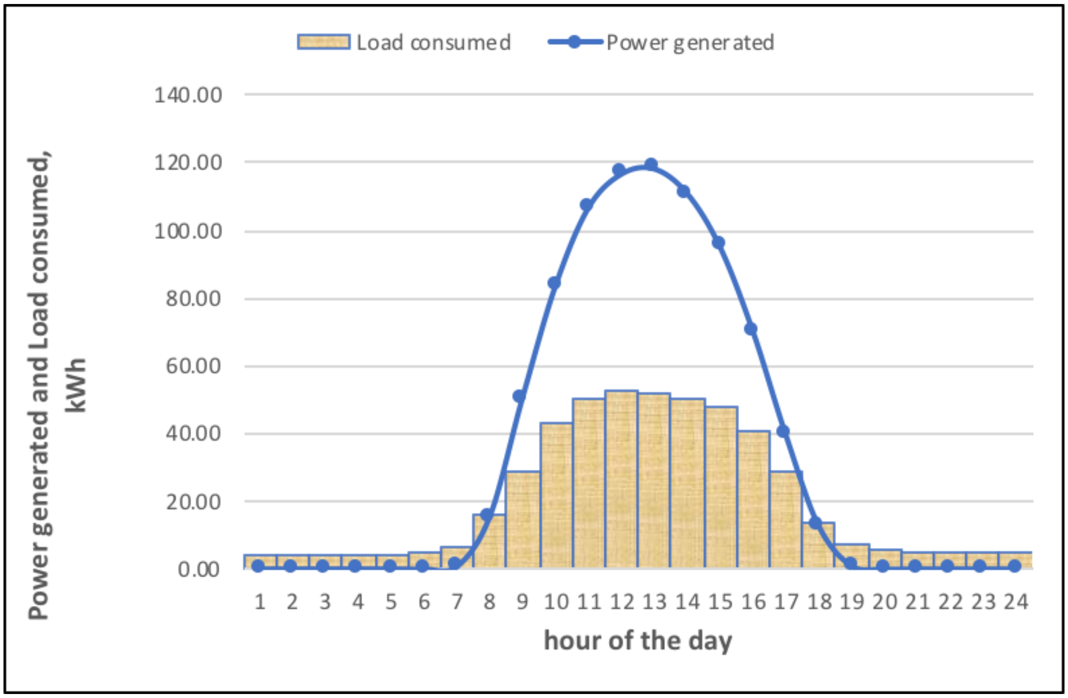
1. Diurnal average daily load and energy generated from 2015 to 2016



2. Diurnal average daily load and energy generated for 2015

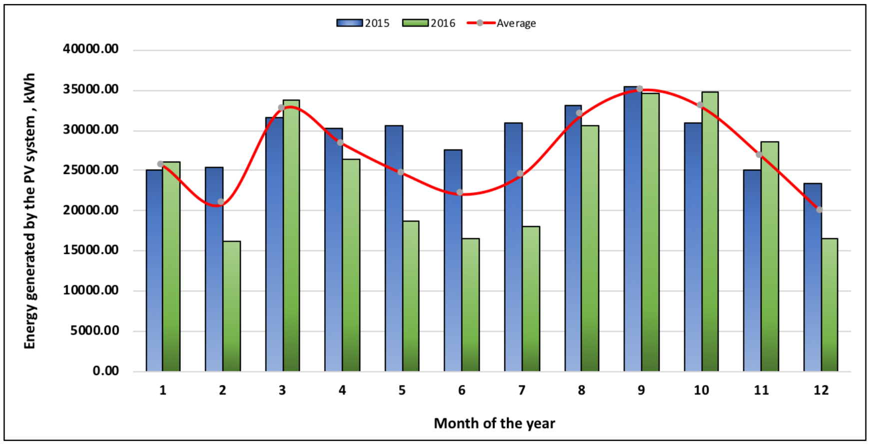


3. Diurnal average daily load and energy generated for 2016

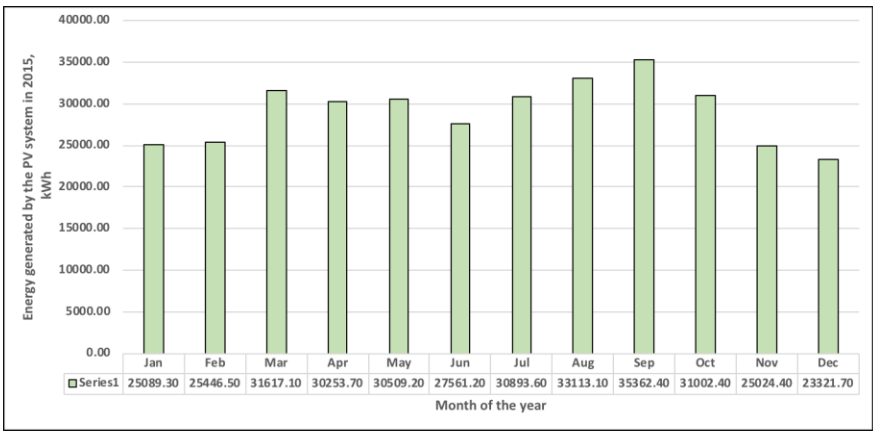


ANNEX C – ENERGY GENERATED BY THE PV SYSTEM

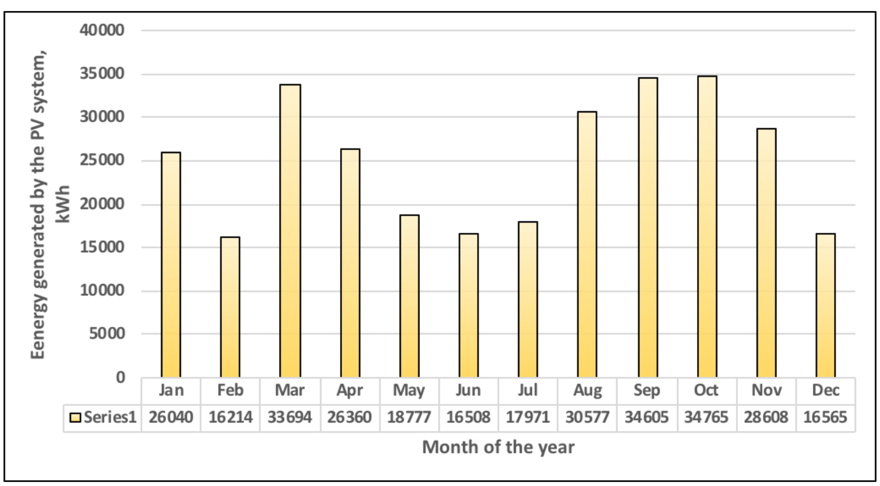
1. **Monthly average energy generated by the PV system from 2015 – 2016**



2. **Monthly average energy generated by the PV system in 2015**



3. **Monthly average energy generated by the PV system in 2016**

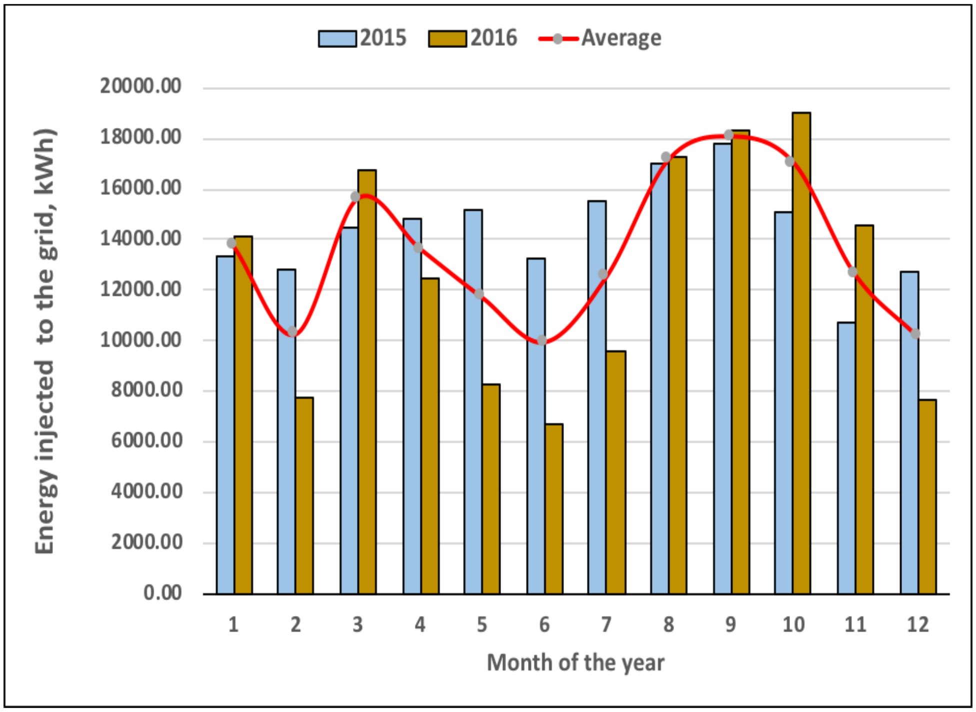


ANNEX D –ENERGY SUPPLY TO THE FEST BUILDINGS BY THE PV SYSTEM, ENERGY IMPORTS FROM AND ENERGY INJECTED TO THE GRID

1. Monthly energy supply by the PV system and energy imports from the grid

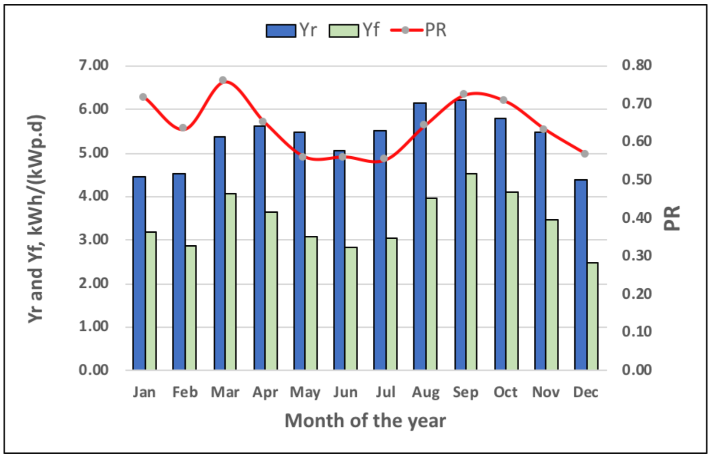
Energy supply by the PV system and energy import from the grid to FEST buildings						
Month	Energy supply by the PV system			Energy import from the grid		
	2015	2016	Average	2015	2016	Average
Jan	11724.30	11912.10	11818.20	4461.56	1895.35	3178.46
Feb	12586.20	8491.07	10538.64	4689.24	4493.99	4591.62
Mar	17095.40	16985.00	17040.20	6030.11	2914.34	4472.23
Apr	15457.10	13861.80	14659.45	5648.27	2679.84	4164.06
May	15320.50	10501.98	12911.24	5764.51	3045.10	4404.81
Jun	14309.70	9798.89	12054.30	5701.82	2935.38	4318.60
Jul	15400.30	8364.53	11882.42	5129.32	1983.71	3556.52
Aug	16123.40	13280.40	14701.90	4841.14	1346.21	3093.68
Sep	17576.00	16290.50	16933.25	4287.91	1989.08	3138.50
Oct	15954.90	15727.10	15841.00	3260.55	1692.21	2476.38
Nov	12636.10	14039.30	13337.70	3874.25	3315.65	3594.95
Dec	10581.30	8900.99	9741.15	2238.59	2139.19	2188.89
Total	**174765.20**	**148153.66**	**161459.43**	**55927.27**	**30430.05**	**43178.66**

2. Monthly average energy injected to the grid

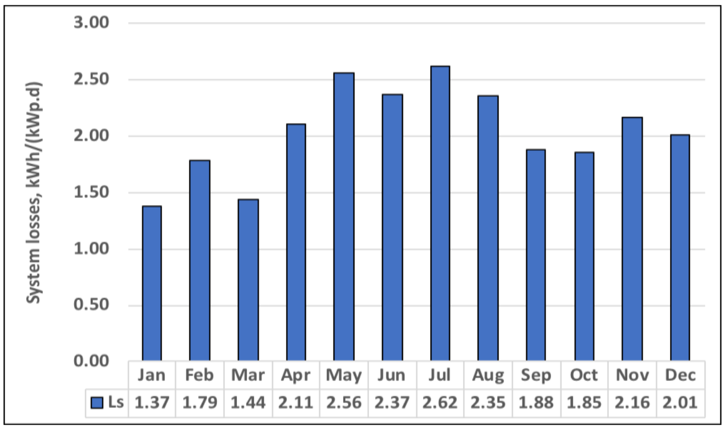


ANNEX E – PERFORMANCE PARAMETERS VALUES

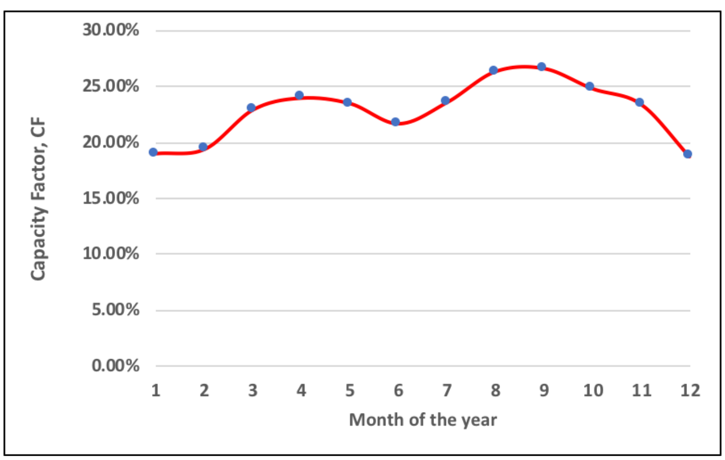
1. **Monthly average, from 2015 to 2016, values of Yr, Yf, and PR**



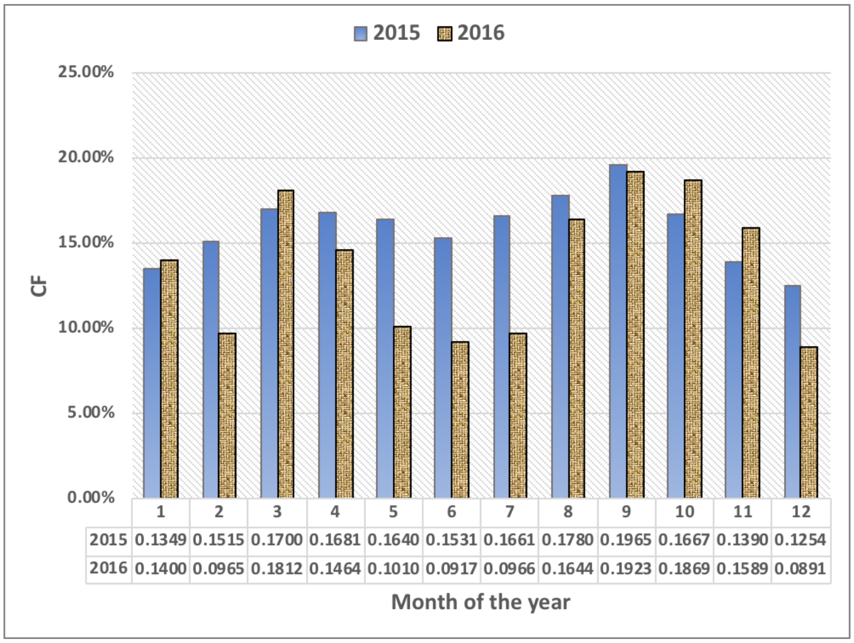
2. **Monthly average, from 2015 to 2016, values of the PV system losses**



3. **Monthly average, from 2015 to 2016, values of the capacity factor**

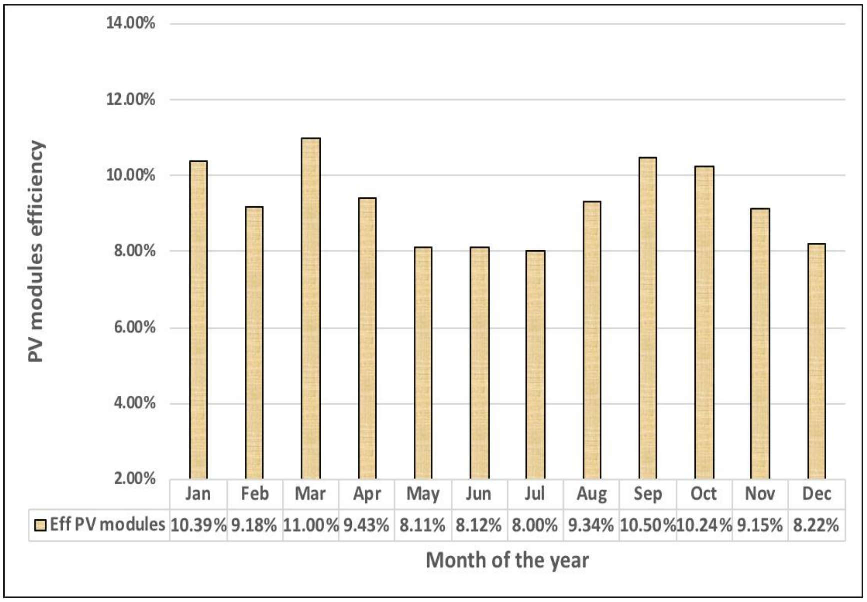


4. Monthly average values of the capacity factor for 2015 and 2016



	1	2	3	4	5	6	7	8	9	10	11	12
2015	0.1349	0.1515	0.1700	0.1681	0.1640	0.1531	0.1661	0.1780	0.1965	0.1667	0.1390	0.1254
2016	0.1400	0.0965	0.1812	0.1464	0.1010	0.0917	0.0966	0.1644	0.1923	0.1869	0.1589	0.0891

5. PV module efficiency of the average data from 2015 to 2016



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eff PV modules	10.39%	9.18%	11.00%	9.43%	8.11%	8.12%	8.00%	9.34%	10.50%	10.24%	9.15%	8.22%

6. Summary of performance parameter values

2015

Month	Metrological parameters		Energies			Energy yields and system losses				PR	CF	Efficiencies		
	Er, (kWh/m^2/day)	Ta, degree C	Energy generated, E_DC, kWh	Energy generated, E_ac, kWh	Eenergy supply to grid, Eg, kWh	Yr, kWh/(kWp.d)	Yf, kWh/(kWp.d)	Ya, kWh/(kWp.d)	Ls, kWh/(kWp.d)			h_{PV}	h_{Inv}	h_{System}
Jan	3.91	26.27	1004.52	809.33	431.13	3.91	3.14	4.02	0.88	0.8013	0.1349	0.1160	0.8057	0.0935
Feb	4.47	25.73	1146.37	908.80	459.30	4.47	3.52	4.59	1.06	0.7885	0.1515	0.1142	0.7928	0.0905
Mar	5.20	26.20	1333.55	1019.91	468.44	5.20	3.95	5.33	1.38	0.7607	0.1700	0.1101	0.7648	0.0842
Apr	5.33	25.77	1367.26	1008.46	493.22	5.33	3.91	5.47	1.56	0.7336	0.1681	0.1062	0.7376	0.0783
May	5.50	25.14	1411.10	984.17	489.96	5.50	3.81	5.64	1.83	0.6937	0.1640	0.1004	0.6974	0.0700
Jun	5.16	25.35	1322.89	918.71	441.72	5.16	3.56	5.29	1.73	0.6907	0.1531	0.1000	0.6945	0.0694
Jul	5.72	25.19	1468.24	996.57	499.78	5.72	3.86	5.87	2.01	0.6751	0.1661	0.0977	0.6788	0.0663
Aug	6.31	24.48	1618.30	1068.16	548.05	6.31	4.14	6.47	2.33	0.6565	0.1780	0.0950	0.6601	0.0627
Sep	6.45	24.87	1653.92	1178.75	592.88	6.45	4.57	6.62	2.05	0.7089	0.1965	0.1026	0.7127	0.0731
Oct	5.85	25.76	1501.37	1000.08	485.40	5.85	3.88	6.01	2.13	0.6625	0.1667	0.0959	0.6661	0.0639
Nov	5.42	28.93	1391.44	834.15	356.19	5.42	3.23	5.57	2.33	0.5963	0.1390	0.0863	0.5995	0.0518
Dec	4.42	28.43	1134.22	752.31	410.98	4.42	2.92	4.54	1.62	0.6597	0.1254	0.0955	0.6633	0.0634
Average	**5.31**	**26.01**	**1362.76**	**956.62**	**473.09**	**5.31**	**3.71**	**5.45**	**1.74**	**0.7023**	**0.1594**	**0.1017**	**0.7061**	**0.0723**

2016

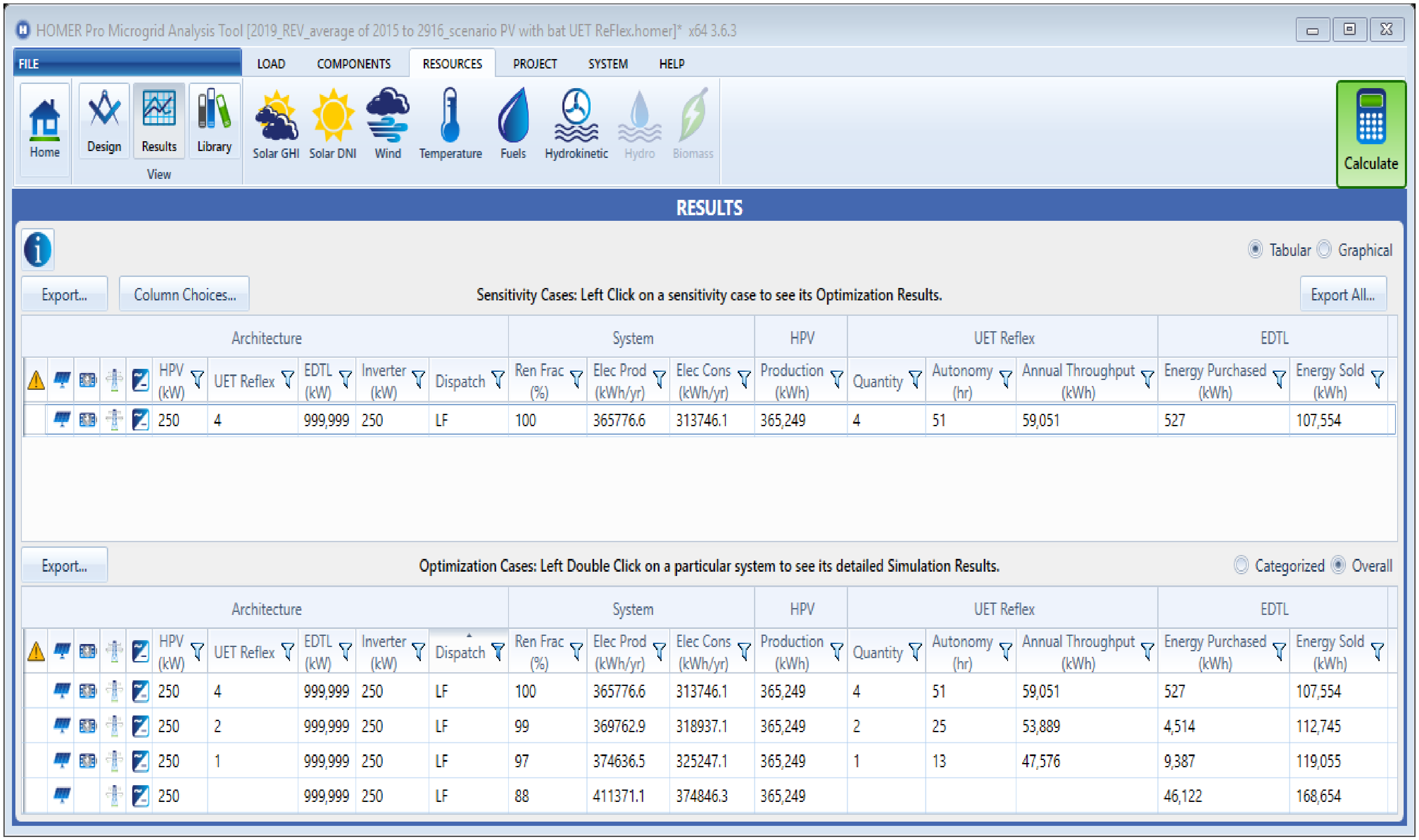
Month	Metrological parameters		Energies			Energy yields and system losses				PR	CF	Efficiencies		
	Er, (kWh/m^2/day)	Ta, degree C	Energy generated, E_DC, kWh	Energy generated, E_ac, kWh	Eenergy to grid, Eg, kWh	Yr, kWh/(kWp.d)	Yf, kWh/(kWp.d)	Ya, kWh/(kWp.d)	Ls, kWh/(kWp.d)			h_{PV}	h_{Inv}	h_{System}
Jan	4.99	28.38	1280.88	839.99	455.73	4.99	3.26	5.12	1.87	0.6523	0.1400	0.0944	0.6558	0.0619
Feb	4.63	27.06	1188.59	579.06	275.81	4.63	2.24	4.75	2.51	0.4846	0.0965	0.0702	0.4872	0.0342
Mar	5.56	27.83	1425.53	1086.92	539.01	5.56	4.21	5.70	1.49	0.7583	0.1812	0.1098	0.7625	0.0837
Apr	5.90	26.87	1515.23	878.66	416.60	5.90	3.41	6.06	2.66	0.5768	0.1464	0.0835	0.5799	0.0484
May	5.50	27.10	1410.70	605.71	266.94	5.50	2.35	5.64	3.30	0.4271	0.1010	0.0618	0.4294	0.0265
Jun	5.00	26.18	1283.66	550.27	223.64	5.00	2.13	5.13	3.00	0.4264	0.0917	0.0617	0.4287	0.0265
Jul	5.33	25.73	1368.45	579.72	309.89	5.33	2.25	5.47	3.23	0.4213	0.0966	0.0610	0.4236	0.0258
Aug	6.04	25.87	1549.65	986.35	557.95	6.04	3.82	6.20	2.38	0.6331	0.1644	0.0917	0.6365	0.0583
Sep	6.02	26.94	1545.52	1153.51	610.49	6.02	4.47	6.18	1.71	0.7423	0.1923	0.1075	0.7464	0.0802
Oct	5.77	27.54	1481.70	1121.46	614.14	5.77	4.35	5.93	1.58	0.7528	0.1869	0.1090	0.7569	0.0825
Nov	5.55	28.37	1423.37	953.60	485.62	5.55	3.70	5.69	2.00	0.6663	0.1589	0.0965	0.6700	0.0646
Dec	4.36	27.59	1119.05	534.34	247.21	4.36	2.07	4.48	2.41	0.4749	0.0891	0.0688	0.4775	0.0328
Average	**5.39**	**27.12**	**1382.69**	**822.47**	**416.92**	**5.39**	**3.19**	**5.53**	**2.34**	**0.5847**	**0.1371**	**0.0847**	**0.5878**	**0.0521**

AVERAGE

Month	Metrological parameters		Energies			Energy yields and system losses				PR	CF	Efficiencies		
	Er, (kWh/m^2/day)	Ta, degree C	Energy generated, E_DC, kWh	Energy generated, E_ac, kWh	Eenergy supply to grid, Eg, kWh	Yr, kWh/(kWp.d)	Yf, kWh/(kWp.d)	Ya, kWh/(kWp.d)	Ls, kWh/(kWp.d)			h_{PV}	h_{Inv}	h_{System}
Jan	4.45	27.33	1142.70	824.66	443.43	4.45	3.20	4.57	1.37	0.72	0.1374	0.1039	0.7217	0.0750
Feb	4.55	26.39	1167.48	743.93	367.55	4.55	2.88	4.67	1.79	0.63	0.1240	0.0918	0.6372	0.0585
Mar	5.38	27.02	1379.54	1053.41	503.73	5.38	4.08	5.52	1.44	0.76	0.1756	0.1100	0.7636	0.0840
Apr	5.62	26.32	1441.24	943.56	454.91	5.62	3.66	5.76	2.11	0.65	0.1573	0.0943	0.6547	0.0617
May	5.50	26.12	1410.90	794.94	378.45	5.50	3.08	5.64	2.56	0.56	0.1325	0.0811	0.5634	0.0457
Jun	5.08	25.76	1303.27	734.49	332.68	5.08	2.85	5.21	2.37	0.56	0.1224	0.0812	0.5636	0.0457
Jul	5.53	25.46	1418.34	788.14	404.84	5.53	3.05	5.67	2.62	0.55	0.1314	0.0800	0.5557	0.0445
Aug	6.17	25.18	1583.97	1027.26	553.00	6.17	3.98	6.34	2.35	0.65	0.1712	0.0934	0.6485	0.0606
Sep	6.23	25.91	1599.72	1166.13	601.69	6.23	4.52	6.40	1.88	0.73	0.1944	0.1050	0.7290	0.0765
Oct	5.81	26.65	1491.53	1060.77	549.77	5.81	4.11	5.97	1.85	0.71	0.1768	0.1024	0.7112	0.0728
Nov	5.48	28.65	1407.41	893.87	420.91	5.48	3.46	5.63	2.16	0.63	0.1490	0.0915	0.6351	0.0581
Dec	4.39	28.01	1126.64	643.33	329.10	4.39	2.49	4.51	2.01	0.57	0.1072	0.0822	0.5710	0.0470
Average	**5.35**	**26.57**	**1372.73**	**889.54**	**445.00**	**5.35**	**3.45**	**5.49**	**2.04**	**0.64**	**0.1483**	**0.0933**	**0.6480**	**0.0605**

ANNEX F – SIMULATION RESULTS OF THE PV SYSTEM WITH BATTERY

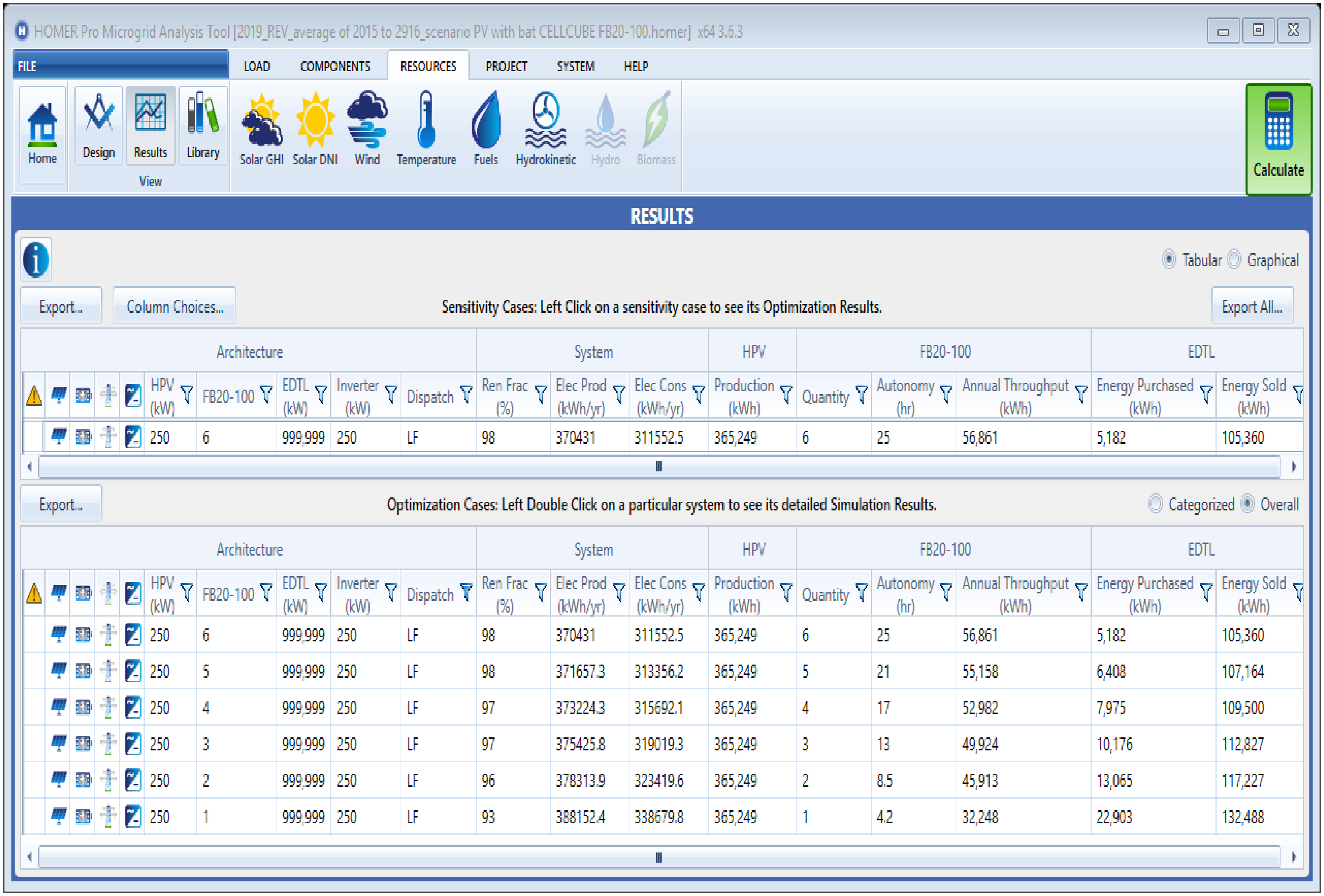
1. Simulation results of the PV system with UET ReFlex-100kW batteries for the average data from 2015 to 2016



Architecture					System			HPV	UET Reflex			EDTL	
HPV (kW)	UET Reflex	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	100	365776.6	313746.1	365,249	4	51	59,051	527	107,554

Architecture					System			HPV	UET Reflex			EDTL	
HPV (kW)	UET Reflex	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	100	365776.6	313746.1	365,249	4	51	59,051	527	107,554
250	2	999,999	250	LF	99	369762.9	318937.1	365,249	2	25	53,889	4,514	112,745
250	1	999,999	250	LF	97	374636.5	325247.1	365,249	1	13	47,576	9,387	119,055
250		999,999	250	LF	88	411371.1	374846.3	365,249				46,122	168,654

2. Simulation results of the PV system with CELLCUBE FB20-100 batteries for the average data from 2015 to 2016



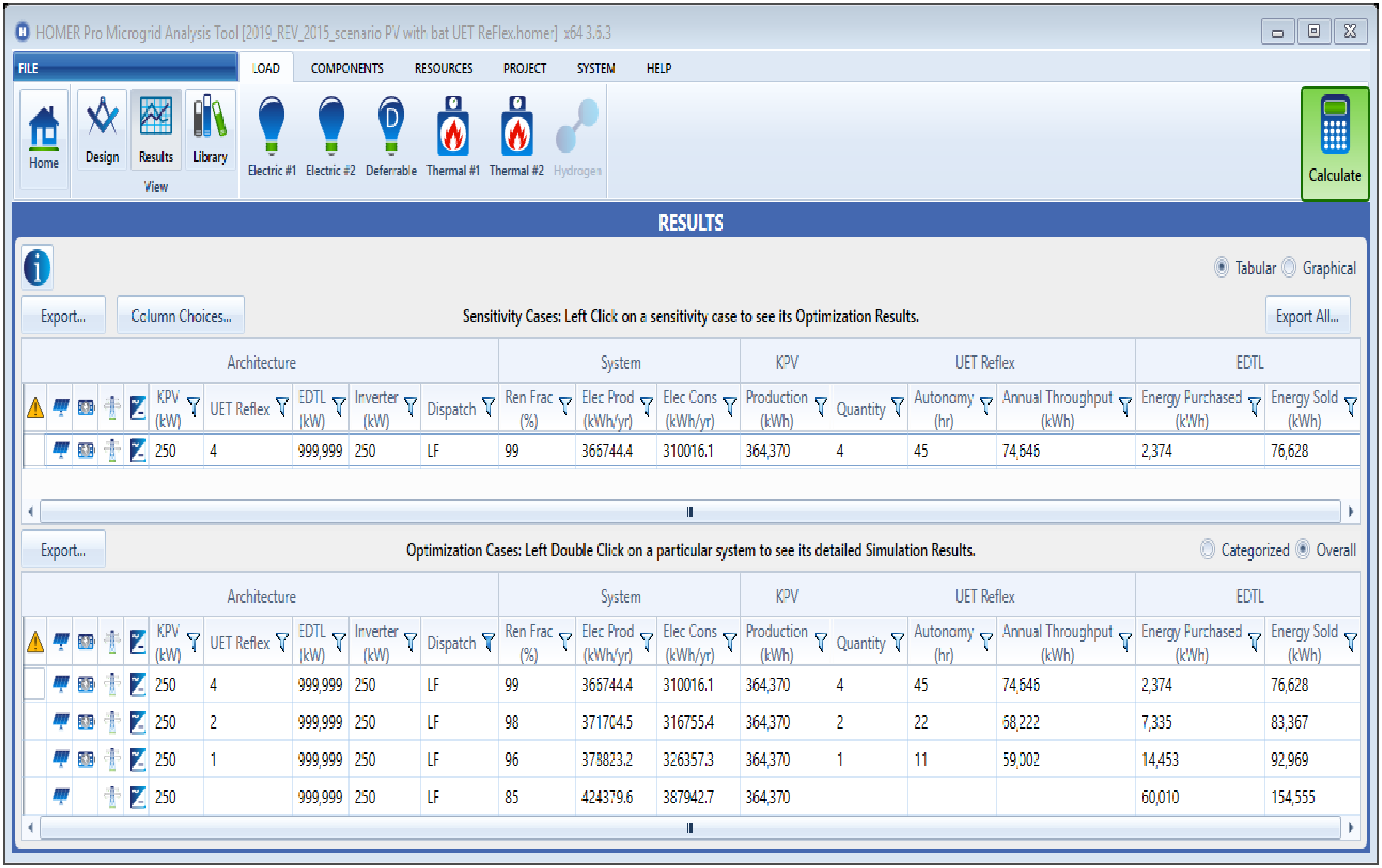
Sensitivity Cases:

Architecture					System			HPV	FB20-100			EDTL	
HPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	98	370431	311552.5	365,249	6	25	56,861	5,182	105,360

Optimization Cases:

Architecture					System			HPV	FB20-100			EDTL	
HPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	98	370431	311552.5	365,249	6	25	56,861	5,182	105,360
250	5	999,999	250	LF	98	371657.3	313356.2	365,249	5	21	55,158	6,408	107,164
250	4	999,999	250	LF	97	373224.3	315692.1	365,249	4	17	52,982	7,975	109,500
250	3	999,999	250	LF	97	375425.8	319019.3	365,249	3	13	49,924	10,176	112,827
250	2	999,999	250	LF	96	378313.9	323419.6	365,249	2	8.5	45,913	13,065	117,227
250	1	999,999	250	LF	93	388152.4	338679.8	365,249	1	4.2	32,248	22,903	132,488

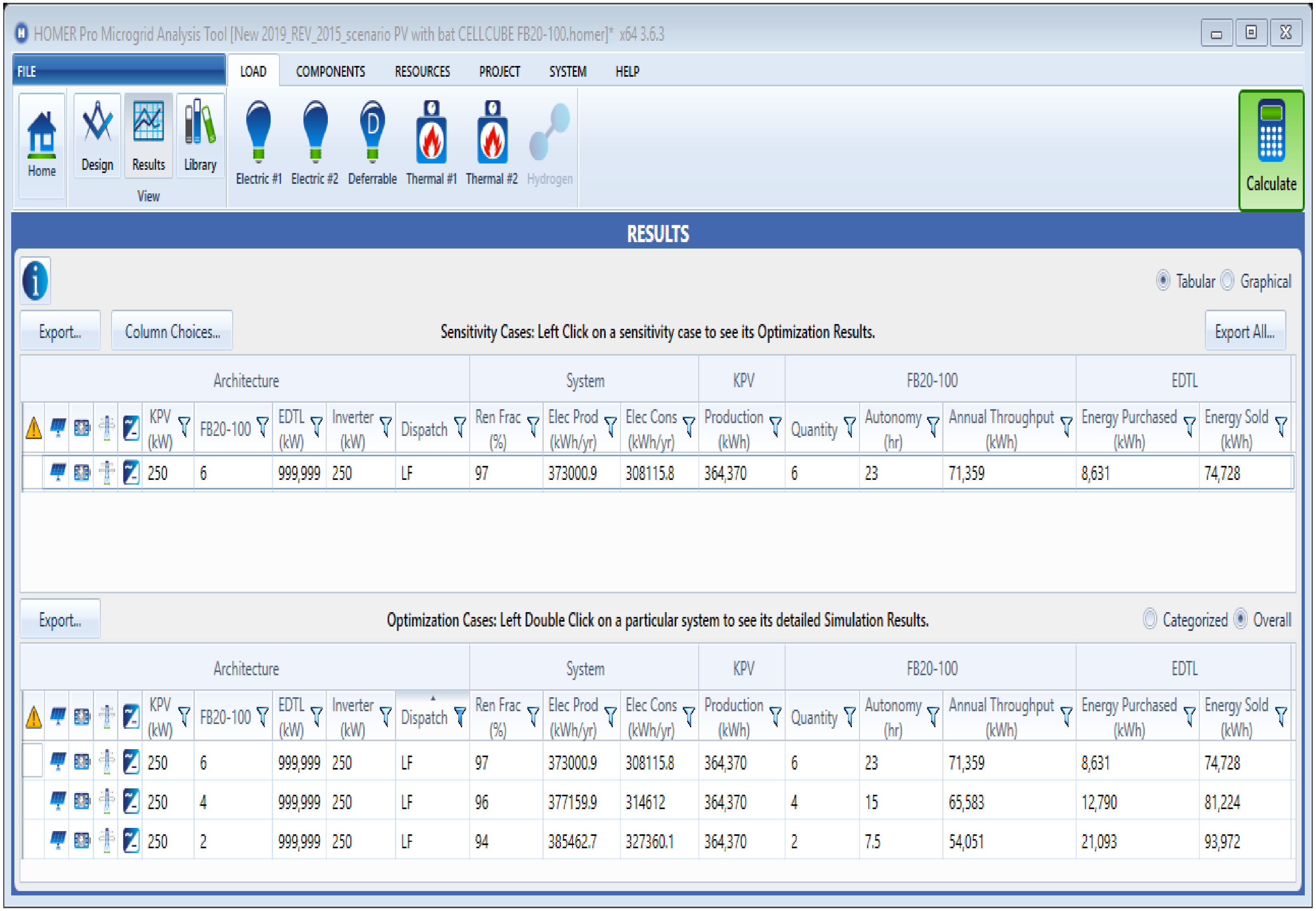
3. Simulation results of the PV system with UET ReFlex-100kW batteries for the average data of 2015



Architecture					System			KPV	UET Reflex			EDTL	
KPV (kW)	UET Reflex	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	99	366744.4	310016.1	364,370	4	45	74,646	2,374	76,628

Architecture					System			KPV	UET Reflex			EDTL	
KPV (kW)	UET Reflex	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	99	366744.4	310016.1	364,370	4	45	74,646	2,374	76,628
250	2	999,999	250	LF	98	371704.5	316755.4	364,370	2	22	68,222	7,335	83,367
250	1	999,999	250	LF	96	378823.2	326357.3	364,370	1	11	59,002	14,453	92,969
250		999,999	250	LF	85	424379.6	387942.7	364,370				60,010	154,555

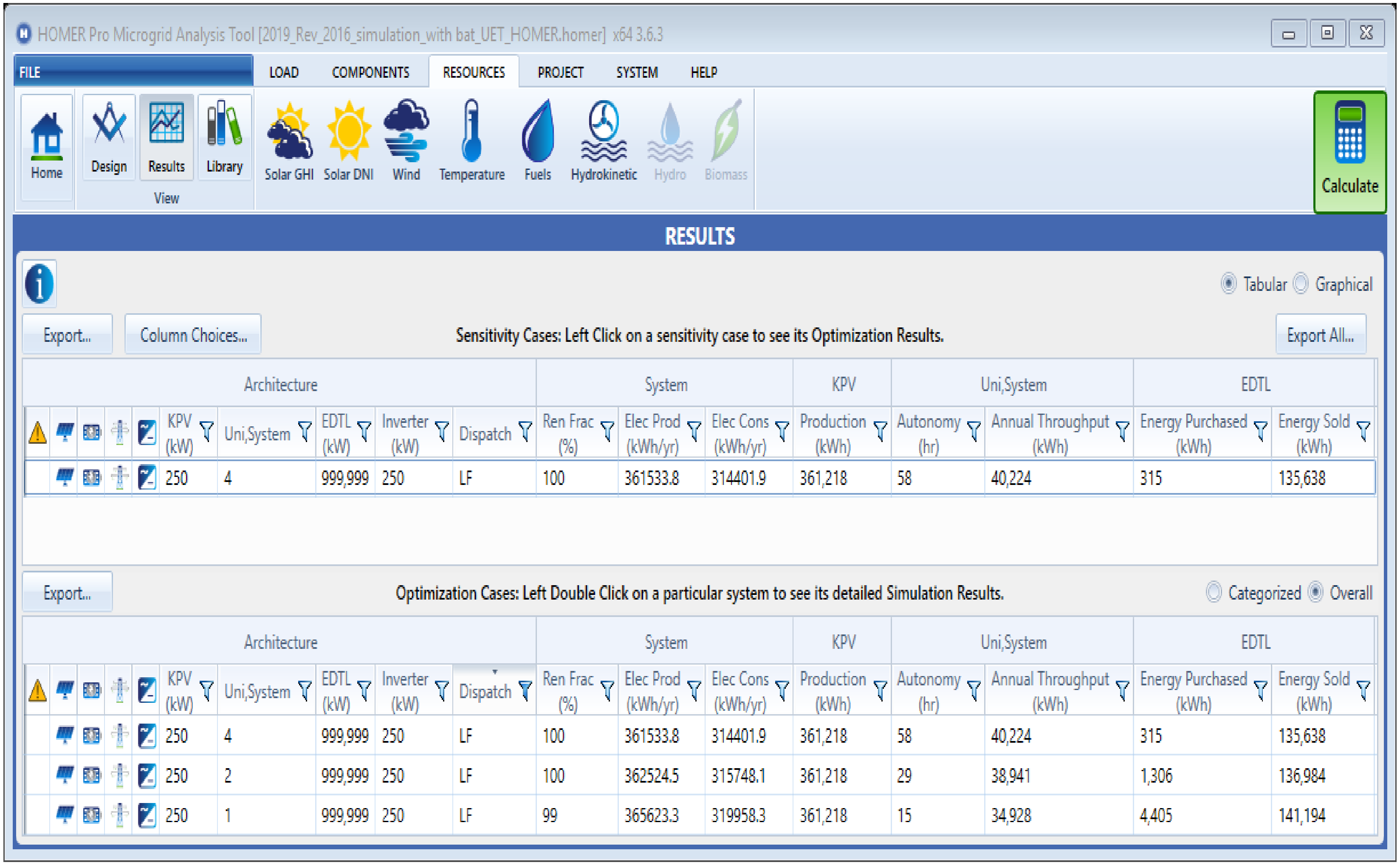
4. Simulation results of the PV system with CELLCUBE FB20-100 batteries for the average data of 2015



Architecture					System			KPV	FB20-100			EDTL	
KPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	97	373000.9	308115.8	364,370	6	23	71,359	8,631	74,728

Architecture					System			KPV	FB20-100			EDTL	
KPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	97	373000.9	308115.8	364,370	6	23	71,359	8,631	74,728
250	4	999,999	250	LF	96	377159.9	314612	364,370	4	15	65,583	12,790	81,224
250	2	999,999	250	LF	94	385462.7	327360.1	364,370	2	7.5	54,051	21,093	93,972

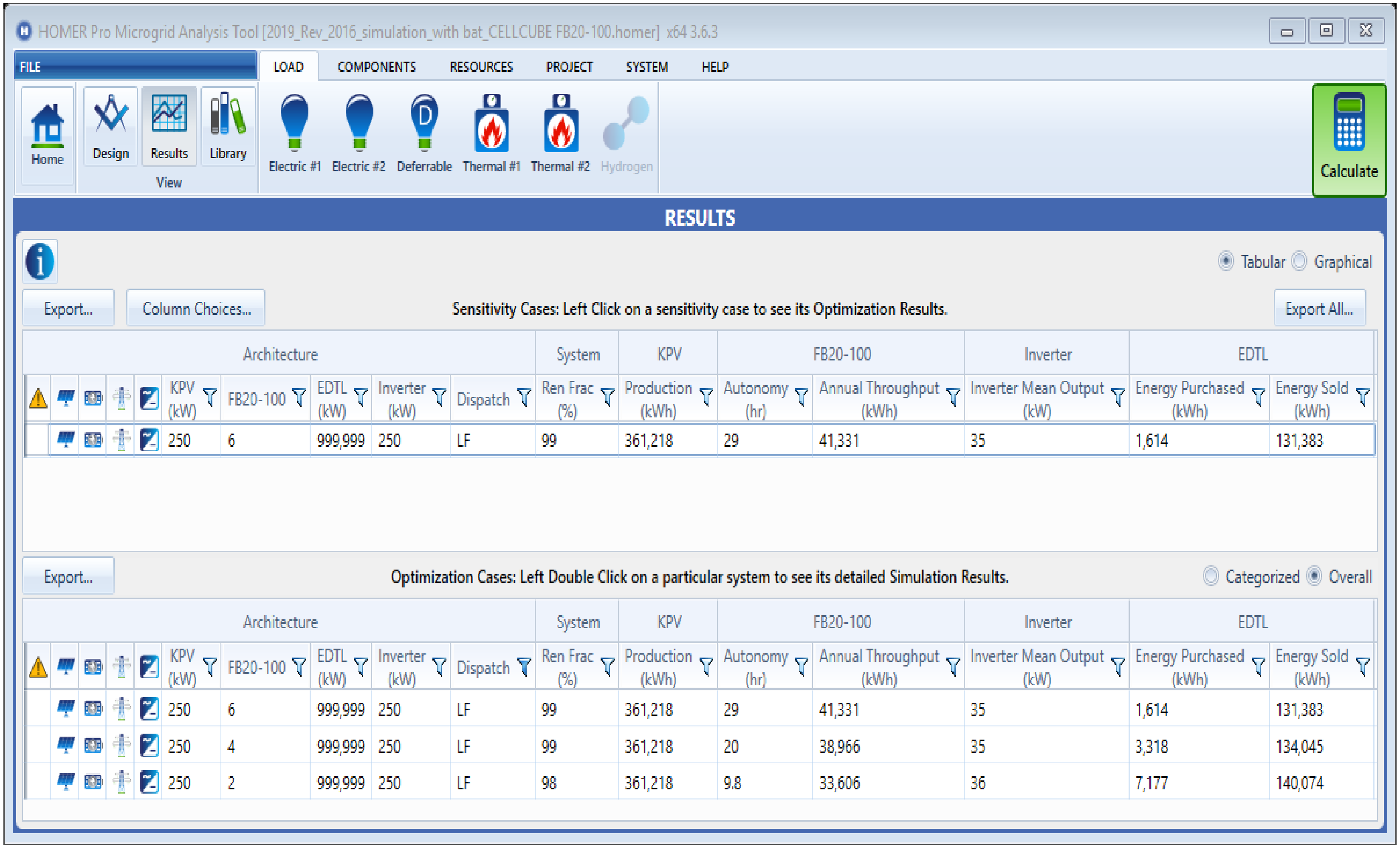
5. Simulation results of the PV system with UET ReFlex-100kW batteries for the average data of 2016



Architecture					System			KPV	Uni,System		EDTL	
KPV (kW)	Uni,System	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	100	361533.8	314401.9	361,218	58	40,224	315	135,638

Architecture					System			KPV	Uni,System		EDTL	
KPV (kW)	Uni,System	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	4	999,999	250	LF	100	361533.8	314401.9	361,218	58	40,224	315	135,638
250	2	999,999	250	LF	100	362524.5	315748.1	361,218	29	38,941	1,306	136,984
250	1	999,999	250	LF	99	365623.3	319958.3	361,218	15	34,928	4,405	141,194

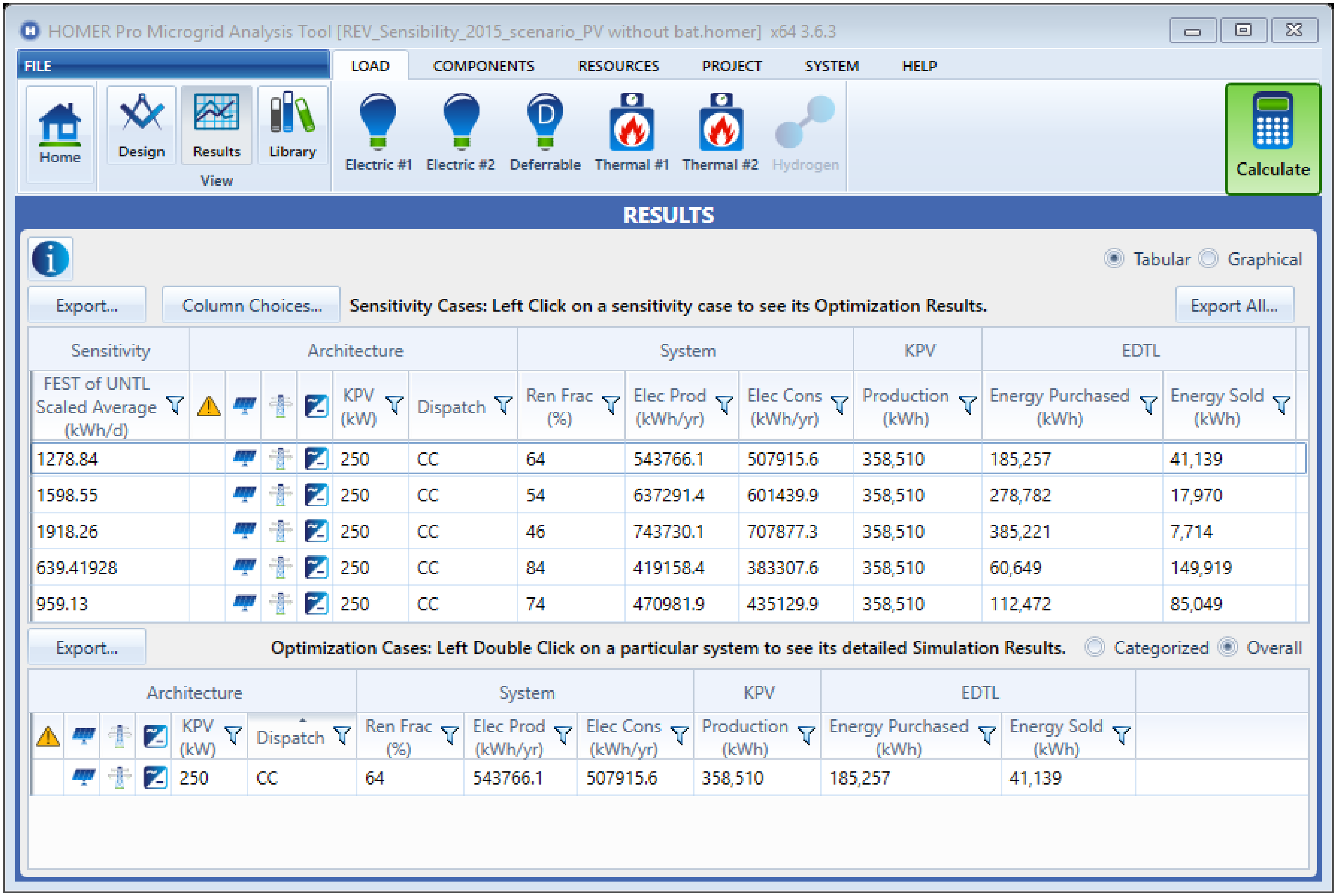
6. Simulation results of the PV system with CELLCUBE FB20-100 batteries for the average data of 2016



Architecture					System	KPV	FB20-100		Inverter	EDTL	
KPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	99	361,218	29	41,331	35	1,614	131,383

Architecture					System	KPV	FB20-100		Inverter	EDTL	
KPV (kW)	FB20-100	EDTL (kW)	Inverter (kW)	Dispatch	Ren Frac (%)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
250	6	999,999	250	LF	99	361,218	29	41,331	35	1,614	131,383
250	4	999,999	250	LF	99	361,218	20	38,966	35	3,318	134,045
250	2	999,999	250	LF	98	361,218	9.8	33,606	36	7,177	140,074

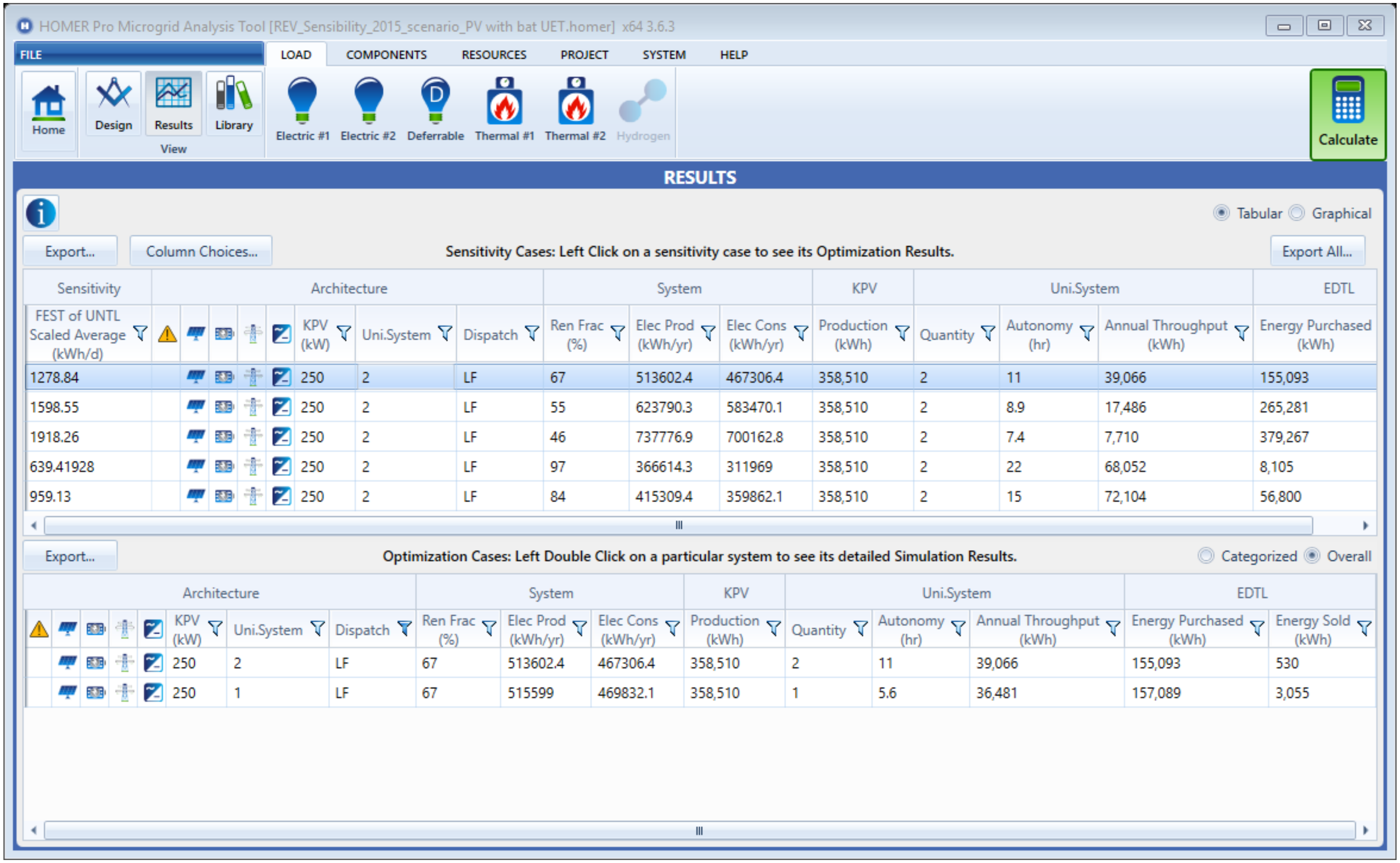
7. Simulation results of the sensitivity analysis of the PV system with load fluctuation



Sensitivity	Architecture		System			KPV	EDTL	
FEST of UNTL Scaled Average (kWh/d)	KPV (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
1278.84	250	CC	64	543766.1	507915.6	358,510	185,257	41,139
1598.55	250	CC	54	637291.4	601439.9	358,510	278,782	17,970
1918.26	250	CC	46	743730.1	707877.3	358,510	385,221	7,714
639.41928	250	CC	84	419158.4	383307.6	358,510	60,649	149,919
959.13	250	CC	74	470981.9	435129.9	358,510	112,472	85,049

Architecture		System			KPV	EDTL	
KPV (kW)	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	CC	64	543766.1	507915.6	358,510	185,257	41,139

8. Simulation results of the sensitivity analysis of the PV system plus battery with load fluctuation



Sensitivity	Architecture			System			KPV	Uni.System			EDTL
FEST of UNTL Scaled Average (kWh/d)	KPV (kW)	Uni.System	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)
1278.84	250	2	LF	67	513602.4	467306.4	358,510	2	11	39,066	155,093
1598.55	250	2	LF	55	623790.3	583470.1	358,510	2	8.9	17,486	265,281
1918.26	250	2	LF	46	737776.9	700162.8	358,510	2	7.4	7,710	379,267
639.41928	250	2	LF	97	366614.3	311969	358,510	2	22	68,052	8,105
959.13	250	2	LF	84	415309.4	359862.1	358,510	2	15	72,104	56,800

Architecture			System			KPV	Uni.System			EDTL	
KPV (kW)	Uni.System	Dispatch	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	Production (kWh)	Quantity	Autonomy (hr)	Annual Throughput (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
250	2	LF	67	513602.4	467306.4	358,510	2	11	39,066	155,093	530
250	1	LF	67	515599	469832.1	358,510	1	5.6	36,481	157,089	3,055

ANNEX G – DIURNAL AVERAGE LOAD DEMAND

1. Diurnal average load demand from 2015 to 2016

HOUR	LOAD OF BUILDING (KWh)		
	2015	2016	Average
1	9.37	4.41	6.89
2	9.18	4.25	6.71
3	9.05	4.16	6.60
4	9.01	4.07	6.54
5	9.00	4.11	6.56
6	9.35	4.78	7.06
7	11.61	6.65	9.13
8	25.43	16.04	20.73
9	37.48	29.01	33.25
10	51.75	42.90	47.32
11	58.47	50.47	54.47
12	60.60	53.04	56.82
13	59.05	52.07	55.56
14	57.72	50.47	54.10
15	56.21	48.30	52.25
16	48.09	40.73	44.41
17	34.95	28.56	31.76
18	18.98	13.61	16.29
19	12.11	7.21	9.66
20	11.68	5.55	8.61
21	10.91	5.19	8.05
22	10.31	5.06	7.68
23	9.87	4.83	7.35
24	9.53	4.65	7.09
TOTAL	**639.69**	**488.31**	**564.91**

2. Diurnal average load demand for 2015

Hour	MONTH OF THE YEAR 2015, kWh												AVERAGE
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0	9.79	10.44	11.74	11.56	11.43	11.25	9.91	9.45	9.07	6.28	7.57	3.90	**9.37**
1	9.69	10.32	11.55	11.31	11.27	11.08	9.69	9.36	8.91	5.97	7.39	3.64	**9.18**
2	9.62	10.26	11.45	11.14	11.14	11.01	9.60	9.25	8.81	5.75	7.11	3.49	**9.05**
3	9.61	10.28	11.37	11.20	11.07	11.01	9.74	9.19	8.72	5.49	6.91	3.54	**9.01**
4	9.63	10.32	11.44	11.15	11.10	11.01	9.80	9.14	8.70	5.31	6.79	3.57	**9.00**
5	9.79	10.49	11.71	11.37	11.33	11.30	10.09	9.53	9.13	6.42	7.40	3.59	**9.35**
6	10.73	11.72	13.80	13.63	13.04	13.04	10.97	11.19	11.71	10.82	12.20	6.40	**11.61**
7	23.87	25.23	30.22	27.51	25.88	24.67	21.21	23.52	28.14	28.03	25.82	21.07	**25.43**
8	33.42	36.77	46.29	40.23	40.92	37.49	35.73	38.27	40.63	35.97	35.44	28.62	**37.48**
9	44.69	46.85	62.58	57.88	54.21	51.62	49.88	53.20	57.72	51.91	51.17	39.28	**51.75**
10	49.29	52.99	70.80	64.50	57.03	56.84	58.53	60.91	66.18	60.76	59.72	44.06	**58.47**
11	48.26	57.61	68.18	63.38	56.48	59.67	62.19	64.54	72.71	66.09	61.55	46.50	**60.60**
12	44.15	55.33	63.71	64.02	57.19	59.22	61.13	64.12	72.11	64.35	59.73	43.57	**59.05**
13	43.53	53.78	65.87	65.65	61.61	57.18	59.70	61.07	69.37	61.36	55.94	37.61	**57.72**
14	40.28	51.66	63.81	56.06	60.33	58.89	60.71	61.77	68.96	59.63	55.15	37.27	**56.21**
15	33.63	43.15	54.61	49.47	52.92	50.41	54.04	53.38	60.00	49.79	44.75	30.96	**48.09**
16	23.53	32.64	40.95	35.53	39.61	38.04	40.63	38.87	44.26	32.77	30.98	21.55	**34.95**
17	16.77	19.38	20.64	19.72	18.94	20.54	21.30	21.83	21.40	16.75	17.28	13.19	**18.98**
18	10.71	12.32	12.71	13.60	12.97	13.76	12.73	13.62	13.01	10.25	11.53	8.14	**12.11**
19	11.08	12.03	13.90	14.35	13.90	13.68	12.03	12.49	11.52	8.60	10.25	6.31	**11.68**
20	11.06	12.01	13.71	13.56	13.40	13.33	11.44	11.34	10.23	7.29	8.83	4.76	**10.91**
21	10.63	11.65	12.86	13.24	12.67	12.40	10.83	10.55	9.56	7.00	8.03	4.27	**10.31**
22	10.34	11.09	12.28	12.49	12.13	11.78	10.30	10.03	9.27	6.79	7.86	4.03	**9.87**
23	9.95	10.67	11.95	11.97	11.81	11.10	10.09	9.73	9.14	6.53	7.73	3.69	**9.53**
TOTAL	**534.05**	**618.97**	**748.13**	**704.53**	**682.38**	**667.12**	**662.27**	**676.38**	**728.82**	**619.90**	**607.10**	**413.71**	**639.69**

3. Diurnal average load demand for 2016

HOUR	MONTH OF THE YEAR 2016, KWh												
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	AVERAGE
1	3.12	4.90	5.21	4.81	5.13	5.24	4.21	2.24	4.24	2.67	7.29	3.89	4.41
2	2.98	4.69	5.00	4.47	5.03	5.28	3.99	2.05	3.97	2.43	7.19	3.89	4.25
3	2.85	4.91	4.91	4.19	4.74	5.01	3.80	1.97	3.79	2.26	7.20	4.23	4.16
4	2.72	4.71	4.66	3.82	4.62	5.03	3.75	1.73	3.74	2.58	7.12	4.33	4.07
5	2.80	5.17	4.98	4.32	4.78	4.94	3.66	1.47	3.56	2.42	7.01	4.22	4.11
6	2.77	6.26	6.02	5.57	5.16	5.80	3.46	2.40	4.43	3.62	7.34	4.48	4.78
7	3.72	6.75	6.59	5.54	5.99	7.84	5.24	5.49	7.06	8.42	10.73	6.39	6.65
8	18.97	18.48	22.92	17.75	11.37	10.20	8.93	11.21	16.95	20.60	21.20	13.90	16.04
9	29.82	27.86	38.93	34.39	23.96	19.17	16.55	24.40	36.40	39.57	35.18	21.94	29.01
10	42.44	39.82	55.83	50.44	37.54	31.93	26.98	41.42	51.72	54.80	51.55	30.33	42.90
11	48.79	43.49	65.91	59.42	44.65	40.52	33.96	51.11	59.45	62.46	59.18	36.75	50.47
12	50.98	46.44	68.47	59.36	47.17	42.77	35.10	55.57	66.79	65.11	59.94	38.73	53.04
13	47.75	46.98	66.72	56.69	44.72	44.41	34.58	54.98	68.82	64.26	58.08	36.86	52.07
14	44.25	45.73	63.92	55.39	43.64	43.65	35.10	53.71	68.66	60.50	55.90	35.24	50.47
15	42.53	44.42	66.43	54.57	40.33	42.25	33.34	52.46	66.85	54.48	49.72	32.21	48.30
16	35.41	38.19	54.40	44.61	35.44	36.28	28.61	45.65	57.00	46.19	41.78	25.26	40.73
17	23.10	27.70	39.13	32.29	25.48	25.82	19.97	30.75	39.60	31.50	30.01	17.38	28.56
18	14.06	13.96	21.38	15.90	11.38	11.50	9.88	13.25	15.27	12.51	14.10	10.11	13.61
19	6.50	8.18	9.55	8.50	7.41	7.47	5.41	5.63	6.80	5.80	9.29	5.93	7.21
20	4.52	5.80	7.05	6.66	6.21	6.33	4.36	3.51	5.37	4.45	8.01	4.32	5.55
21	4.00	5.58	6.50	6.16	5.79	6.01	4.17	3.00	4.92	4.34	7.87	3.97	5.19
22	3.89	5.22	6.13	5.97	5.66	5.66	4.46	2.96	4.93	3.99	7.77	4.08	5.06
23	3.88	5.07	5.71	5.49	5.47	5.77	4.29	2.46	4.64	3.68	7.57	3.96	4.83
24	3.56	4.89	5.56	5.11	5.31	5.60	4.26	2.40	4.46	3.32	7.52	3.76	4.65
TOTAL	**445.40**	**447.77**	**641.91**	**551.39**	**437.00**	**424.47**	**333.81**	**471.82**	**609.41**	**561.97**	**578.56**	**356.14**	**488.31**

4. Diurnal average energy generated by the System

HOUR	ENERGY GENERATED (kWh)		
	2015	2016	Average
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.42	0.68	0.55
8	15.68	15.40	15.54
9	57.53	50.68	54.11
10	97.78	83.78	90.78
11	121.96	106.88	114.42
12	133.75	116.90	125.33
13	138.28	118.49	128.38
14	132.97	111.23	122.10
15	112.81	95.41	104.11
16	84.75	70.46	77.60
17	48.24	39.80	44.02
18	15.39	12.79	14.09
19	1.11	0.92	1.01
20	0.00	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
TOTAL	**958.17**	**850.13**	**892.04**

5. Diurnal average energy generated by the system for 2015

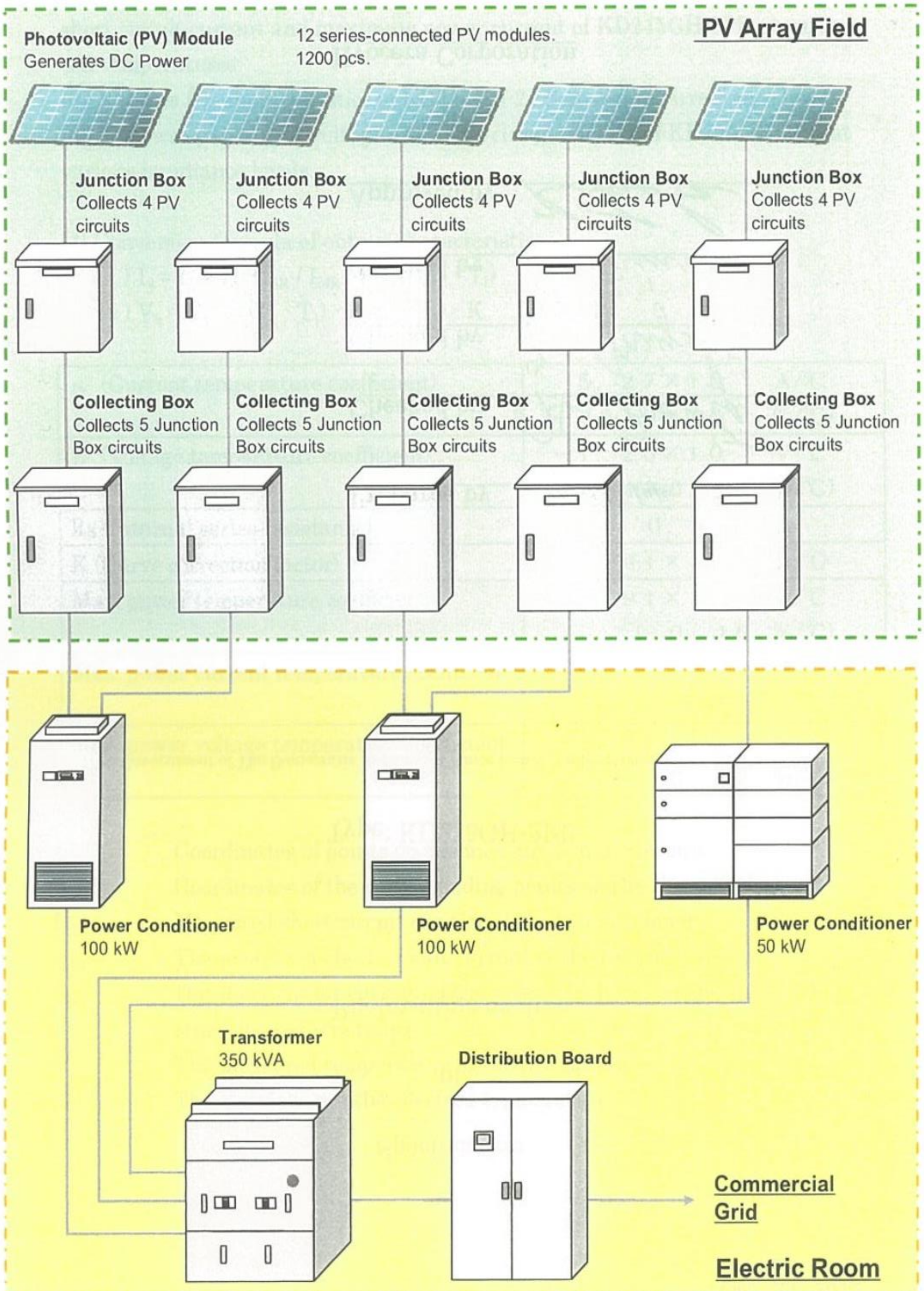
HOUR	MONTH OF THE YEAR, kWh												AVERAGE
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
7	0.29	0.04	0.03	0.04	0.02	0.00	0.00	0.01	0.28	1.55	1.67	1.10	**0.42**
8	17.60	14.57	16.22	13.84	10.51	6.78	5.29	10.87	22.62	27.13	21.70	21.05	**15.68**
9	54.87	55.57	66.50	61.53	58.66	46.80	46.36	56.86	72.40	63.52	53.51	53.79	**57.53**
10	86.97	84.63	111.03	108.74	101.22	92.02	93.45	104.77	117.41	102.66	87.01	83.47	**97.78**
11	103.84	110.31	138.75	135.23	122.02	114.03	122.25	133.50	144.59	131.06	108.33	99.61	**121.96**
12	107.66	130.43	142.96	142.65	129.81	129.11	135.35	148.98	161.92	143.05	120.48	112.62	**133.75**
13	110.19	138.54	133.73	149.63	137.32	135.96	145.62	157.47	168.90	146.73	123.66	111.61	**138.28**
14	116.26	129.17	134.00	145.89	139.08	128.96	143.94	149.01	160.88	135.90	117.16	95.46	**132.97**
15	96.26	106.47	119.60	103.04	121.27	116.23	126.93	128.01	141.21	115.71	94.76	84.19	**112.81**
16	69.82	71.96	87.28	83.14	97.71	89.68	101.62	100.77	109.65	80.55	63.86	60.96	**84.75**
17	35.66	45.34	53.49	47.16	58.07	50.63	59.39	59.51	62.90	41.07	32.63	33.03	**48.24**
18	18.73	22.70	18.85	16.14	12.80	12.88	16.03	17.94	15.64	11.01	9.16	12.76	**15.39**
19	3.25	3.69	1.78	1.45	0.15	0.15	0.34	0.45	0.34	0.14	0.20	1.33	**1.11**
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
TOTAL	**821.39**	**913.42**	**1024.23**	**1008.46**	**988.65**	**918.71**	**996.57**	**1068.16**	**1178.75**	**1000.08**	**834.15**	**752.31**	**958.74**

6. Diurnal average energy generated by the system for 2016

HOUR	MONTH OF THE YEAR, kWh												AVERAGE
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.13	0.05	0.05	0.04	0.02	0.00	0.00	0.02	0.40	2.41	3.75	1.29	0.68
8	15.99	14.90	16.80	12.16	6.19	4.03	3.48	10.55	23.06	35.42	31.43	16.09	15.84
9	50.19	60.07	65.69	56.54	31.33	24.45	27.16	50.85	73.80	83.99	69.47	36.07	52.47
10	84.60	93.18	102.52	96.67	62.52	50.91	57.16	96.91	113.14	123.72	104.25	53.09	86.55
11	109.30	112.06	136.75	121.50	82.12	71.35	78.24	124.36	136.05	149.08	130.95	70.82	110.21
12	119.05	131.12	151.35	123.94	90.27	76.33	86.33	140.72	159.23	160.99	135.04	78.08	121.04
13	117.52	129.41	155.04	124.16	87.88	84.63	85.21	144.53	166.92	162.15	133.53	76.72	122.31
14	112.43	123.62	147.78	117.98	83.77	78.82	81.64	135.88	157.66	143.92	123.70	71.75	114.91
15	98.35	101.21	134.78	97.56	69.54	70.35	73.95	121.86	139.32	114.82	99.26	60.06	98.42
16	75.54	72.45	96.81	70.01	53.53	52.41	56.75	94.51	103.57	83.47	71.33	38.44	72.40
17	39.45	40.52	55.20	42.63	30.50	28.86	33.31	51.49	60.87	48.17	38.77	20.82	40.88
18	15.40	14.53	21.47	14.54	7.91	7.94	9.98	14.35	18.80	13.00	11.51	9.72	13.26
19	2.02	2.64	2.69	0.92	0.13	0.20	0.30	0.33	0.68	0.32	0.61	1.38	1.02
20	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	**839.99**	**897.22**	**1086.92**	**878.66**	**605.71**	**550.26**	**593.51**	**986.35**	**1153.51**	**1121.46**	**953.60**	**534.34**	**850.13**

ANNEX H – PV SYSTEM CONFIGURATION AND MANAGEMENT SYSTEM

1. PV system configuration



2. Diagram of PV system data management and control system